There's Adventure in

atomic energy

Julian May

$2.50

There's Adventure in ATOMIC ENERGY

Randy Morrow, the central character in THERE'S ADVENTURE IN ATOMIC ENERGY, is an average American boy in his early teens. His father is a writer of science books, and step by step he introduces Randy to the mysteries and wonders of the world of the atom.

Perhaps the greatest of the new sciences is the development and control of atomic energy. As Randy finds out, here is the fuel to power the industries of the world by the time he has become a man. Here, too, may be the power that will some day take man to the stars.

Randy learns some of the atom's supreme powers by simple experiments which any reader of this book can perform, too.

THERE'S ADVENTURE IN ATOMIC ENERGY

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THERE'S ADVENTURE IN ELECTRONICS

THERE'S ADVENTURE IN CHEMISTRY

There's adventure in

atomic energy

by JULIAN MAY

Illustrated by FRANK C. MURPHY

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CONTENTS

FOREWORD

To the Reader:

This book will take you on a series of adventures in atomic energy. You'll find out what it's like to be a part of this wonderful new field. By learning a few of the basic principles of the science, and by performing the exciting experiments, you should be able to determine whether you'd like a career in atomic energy.

Before you do the experiments, you should be aware that atomic energy isn't for the careless.

You would not deliberately hold your finger in a flame, or drink a bottle of iodine. These things can be harmful if they are not handled carefully. It is the same with radioactive substances. Radium paint from the dial of a clock should not be allowed to touch your bare skin. It is harmful if breathed, swallowed, or rubbed into an open sore. However, if you scrub your hands and tools after performing the experiments, and if you are careful not to spread the paint dust into the air, it will not harm you. Any radium paint left over after your experiments can safely be gotten rid of by flushing it down the toilet.

Thousands of people work safely with atomic energy every day. You can too. Perform your experiments carefully, and you'll find it very true that . . . *There's Adventure in Atomic Energy*.

J. M.

Chicago, Illinois

ACKNOWLEDGMENTS

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Special thanks is due to Glen Sandberg, University of Illinois, for designing the young people's geiger counter especially for this book.

Chicago, Illinois J.M.

CHAPTER 1

Atoms and geigers

RANDY MORROW made a quick survey of the camping department of the store. No luck. He hurried into the skin-diving equipment section. A salesman was squatting on the floor, picking up some swim fins that had fallen off the counter.

"Say, mister," Randy said, "did you see a little kid about nine years old? With a crew cut and a red jacket?"

"I'll say," the man growled. "He was poking around these fins and knocked the whole pile down. He ran into the next room."

Sure enough. Randy found his brother Sam kneeling beside a large showcase, nose pressed tightly to the glass.

"You're really going to catch it when Dad finds out you ran away again," Randy said.

Sam cut him off. "Look at the stuff in here, Randy! Wow! Geiger counters!"

"In a sporting goods store?" Randy scoffed. "Move over. Let me look."

Sam was right. The big case was filled with different kinds of instruments. They were all sizes—small, thin ones only about as large as a book; big heavy looking devices with mysterious dials and switches; even some in leather cases with straps for carrying.

"Look at this one!" exclaimed Sam to his older brother. "It looks like a ray gun! And it's not a geiger counter, either. The sign says skin— skin—"

"Scintillation counter," said Randy. "*Sin*-tillation. Dad's friend Mr. Wood was talking about them one evening when he was over. It's something like a geiger counter, only it's more sensitive. Wow! Look at that price!"

"Four hundred and ninety-five *dollars!*" yelled Sam. "For a little thing like that? Who'd pay that much for a sin-scintillation counter?"

"A uranium prospector," said another voice.

"Dad!" the boys exclaimed.

"I could recognize Sam's bellowing half-way across the store," Mr. Morrow said. "I thought I left you guys in the baseball section."

Randy said, "This character had to see the geiger counters. Gee, Dad, you mean that prospectors buy their geiger counters here?"

"That's right. Quite a few big sporting goods stores carry radiation monitoring equipment like this. Prospecting for radioactive ore is a popular hobby these days."

Sam looked mystified. "How do these things work?"

Mr. Morrow said, "Let's ask a salesman to show us."

Since it wasn't a very busy day in the store, the salesman was glad to pass the time by showing the Morrows how the instruments worked.

"My name's Barnett," he introduced himself. He lifted a boxlike device out of the showcase. "Now here's one of our most popular geiger counter models. Very simple to operate. Nice and light, too."

Suddenly Randy cried, "I hear something!"

The geiger counter looked like a small metal box with a handle on top. The handle served as a resting place for a metal cylinder that was connected to the box by a rubber-covered cable. On top of the box was a meter, a switch, a jack to plug headphones into, a small light, and a plug marked "calibration."

"Okay," said Barnett. "First we check to be sure all the parts are here. Now plug in the headphones." He held the phones out to Randy. "Suppose you put these phones on, young man."

He held up the cylinder that was attached to the cable. "This is the geiger tube. It's a special kind of glass tube mounted in a metal case. You turn the metal shield, like this, until part of the glass is exposed. I'll turn the counter on."

The little light on top of the geiger counter began to blink slowly.

Suddenly Randy cried, "I hear something."

"What? What?" Sam wanted to know. "Let me listen, too!"

"Easy does it," said the salesman kindly. "You'll have your turn. What your brother hears is the background radiation that's always present in the air. I turned on the instrument, so the geiger tube is counting the particles of radiation that pass through it."

"Radioactive air? In here?" Sam looked alarmed.

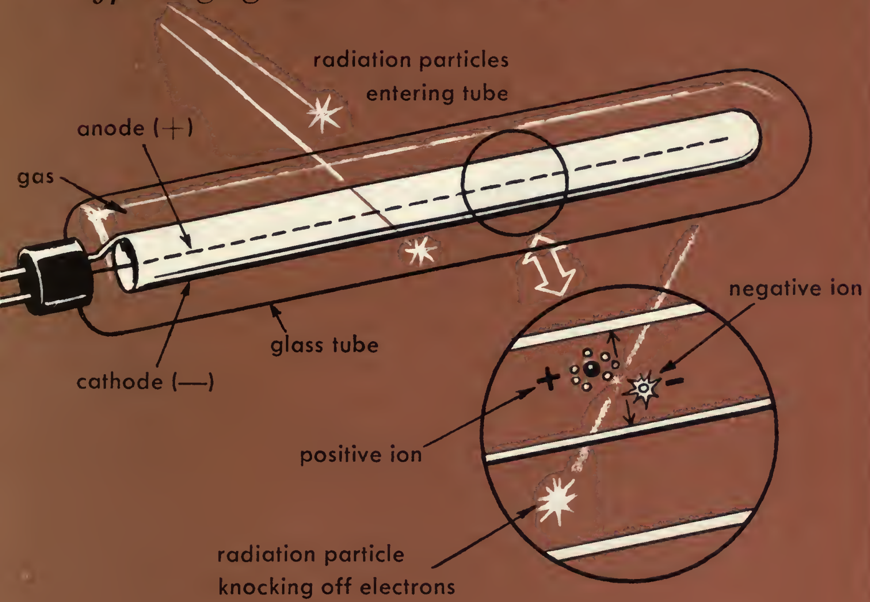
Mr. Morrow smiled. "Nothing to hurt you, son. There's radioactivity all around us. Some of it comes from rocks in the ground. Some comes from outer space—that's called cosmic rays. Nowadays, there's radiation in the air from man-made sources of radioactivity."

Randy said, "You know, like from bomb testing and from atomic plants."

The salesman continued. "Now if you were searching for something radioactive, you'd adjust the selector switch on the counter to its most sensitive scale. Then you aim this geiger-tube probe at rocks or other things."

Randy asked, "Mr. Barnett, what happens when a little bit of radiation hits the geiger tube?"

A typical geiger tube in action



Particles of radiation strike molecules of gas in the tube, forming ions. Negative ions travel to anode, positive ions to cathode, causing a spurt of electricity to flow.

"Well, inside the glass tube is a metal cylinder that carries a negative charge of electricity. Running through the center of the cylinder is a wire filament that's positively charged. The cylinder is called the *cathode* and the filament is the *anode*. The tube is filled with a special kind of gas."

"Sounds something like a radio tube," remarked Randy.

"Something like it, but not quite the same. When a particle of radiation enters the geiger tube, it hits some of the gas atoms and knocks off some of their electrons. These

atoms with their electrons missing have a positive charge. The knocked-off electrons have a negative charge. Now you know that opposite kinds of electricity attract each other. So what do you suppose happens to the pieces of the gas atoms?"

Randy thought for a minute. "I guess the negative electrons would travel to the positively charged wire, and the positive atom would go to the negatively charged cylinder."

"Right," Barnett said. "And when they do, they cause a little spurt of electricity to flow. Each radiation particle that enters the tube knocks the electrons off several atoms, so an electric pulse large enough to be amplified and measured is produced. Each pulse causes the light to flash, the meter to jump, and a click in the headphones."

"Pretty neat," said Sam.

"What's this calibration plug for, Mr. Barnett?" Randy asked.

"I'll show you." He got out a little plastic-covered disk. "This is a standard calibrating source. Calibrate just means *measure.*"

He handed the disk to Randy. "The little disk contains a tiny bit of radioactive material that has been measured accurately at the Bureau of Standards in Washington. We know that this source gives off one point two milliroentgens of radiation per hour."

"Milly who?" asked Sam.

"*Rent*-gen," repeated Mr. Barnett. "It's just a unit for measuring radioactivity—like inches measure length."

"I see," said Randy.

"Just call it an m.r.," suggested Mr. Barnett. "Now hold the tube up against the center of the probe."

"Hey, more clicks!" Randy exclaimed.

Ionization-chamber radiation detector

Called "Juno," this instrument can measure alpha, beta, and gamma radiation. A chamber inside the Juno contains two electrodes with a voltage applied. Radiation ionizes the air in the chamber, and the ions travel to the electrodes. The electrical current produced is measured and shown on the meter, which reads directly in milliroentgens per hour. The knob on the left varies the range of the meter and also its sensitivity. This meter has a range of 0-50, 0-500, and 0-5000 m.r. an hour.

Mr. Morrow said, "Watch the meter, son. See if the instrument gives the correct reading."

"It doesn't seem to be right," Randy observed.

Mr. Barnett explained. "First you have to note the background count. That's the number of counts per minute from natural radioactivity in the air. *Then* you put the calibrating source against the probe. Subtracting the background count from the calibrating source reading should give almost ex-

actly the value that's stamped on the source."

"Sharp," said Randy.

"If the instrument was off the beam a little, we'd adjust the calibration plug with a screwdriver. Prospectors carry their calibration sources with them so that they can check their instruments frequently. Lots of men have blown their corks when their big bonanza uranium strike turned out to be nothing but an offbeam geiger!"

"My turn to wear the headphones," Sam demanded.

Randy placed the phones over his brother's ears.

"Wow! Listen to the clicks!"

Mr. Barnett took the calibrating source away from the probe. "Suppose you go on a hunt for radioactive treasure, young man."

"Oh, boy!" said Sam.

"In one of these drawers behind the showcase, there's a big chunk of carnotite. That's a mineral ore of uranium. See if you can tell which drawer it's in."

Frowning seriously, Sam started his search.

Randy said, "Prospecting must be a lot of fun, Dad."

"There's a lot more to atomic energy than prospecting for uranium. It's a big, fascinating field. Besides atomic research, there's the field of atomic power, radioactive isotopes used in industry, agriculture, and medicine, radiation sterilizing of food, and of course, atomic weapons."

"I'd like to find out more about it," Randy said. "But, gee—I could never afford any of *these* instruments."

"There are a lot of atomic experiments you can do without expensive equipment. If you like, I can help you with some."

"That'd be swell, Dad."

The salesman asked, "Are you a scientist or something yourself, sir?"

Mr. Morrow laughed. "Nope. Just a science writer. I would've been a scientist, but I just couldn't get that math. Writing about science seems to be the next best thing."

"Dad does articles for the newspapers and for magazines," Randy said proudly.

Suddenly there was a loud, "Ya-*HOO!*" Mr. Barnett clapped his hands over his ears.

"I found it! I found it!" Sam yelled.

"I found it! I found it!" Sam yelled.

"Sam Morrow!" the boys' father said sharply.

Sam began to whisper loudly. "It's in here! See? In this drawer! The needle on the meter really began to kick up

a storm when I brought the probe near this drawer!"

"I guess you win the award for Geigerman of the Year," smiled the salesman.

"Also Loudspeakerman of the Year," muttered Randy.

Mr. Barnett removed the headphones from Sam's ears and turned off the geiger counter. He showed the boys the piece of carnotite. It was a heavy, dark rock with veins of yellowish material running through it.

"The yellow streaks are the real carnotite," he explained. Then he glanced at his watch. "Well, time for my lunch, boys. Guess we'll have to put this stuff away."

Randy said, "Thanks a lot for showing it to us, Mr. Barnett."

"No trouble at all. Come back again some time."

Randy, Sam and Mr. Morrow were heading for home in the car, when Sam came up with a question.

"Dad, I think I've got these geiger counters all figured out except for one thing."

"What's that, son?"

"Where does the counter put them when it's finished?"

Randy asked, "Put *what*, Tiger?"

Sam said, "The geigers. Where does it put the geigers when it's finished counting them?"

Randy and Mr. Morrow exploded into laughter. "Oh, no!" Randy said.

"What's so funny?" Sam muttered.

Mr. Morrow said gently, "Geiger was the name of one of the men who invented the device, Sam. It counts particles of radiation."

Randy was still laughing. "Counting geigers! Oh, brother!"

"If you boys are really interested in atomic energy, we'll make another kind of radiation detector when we get home.

That is, if Randy can control himself."

"Suddenly, I'm solemn. Like an owl."

"You mean you don't give a hoot?" Mr. Morrow asked slyly.

"Ouch!" Randy winced. "I deserved that. But I *do* want to make a radiation detector. Come on, Dad. Let's zoom!"

They zoomed.

CHAPTER 2

Radiation is everywhere

RANDY pried carefully at the glass covering the face of the old alarm clock. Easy does it, now . . .

"Whatcha doing, Randy?"

Smash!

Randy sat back, exasperated, and glared at his little brother Sam. "Now look what you made me do. Glass all over the table."

"Go on," said Sam. "I didn't do a thing. Besides, that old clock hasn't worked for a year. Not since— since—"

"Say it. Since you spilled orange pop on it and rusted the works solid."

Sam snorted. Randy resumed work on the damaged clock. He covered his fingers with a handkerchief as he removed the pieces of broken glass from around the face. At last the job was done.

"All finished," he announced. "You are looking at the raw material for the Morrow Atomic Laboratory."

"Huh?"

Randy got out his pocket knife. Taking a clean, white saucer, he tilted the clock face over it and began to scratch at the numerals with his knife. A fine, yellowish dust began to fall. Randy was careful not to get the dust in his nose or mouth.

"This clock has a radium dial," Randy said. "This stuff I'm scraping off is radioactive."

"Look out!" cried Sam, leaping back. A chair toppled over with a crash.

"Don't be scared. It can't hurt you if you're careful. There's only a tiny little bit of radium in it. But be very careful not to swallow it, or sniff up the dust. When I get done, I'm going to scrub my hands and my knife with soap and a brush. You *always* should scrub your hands after using radium paint. And never touch it. Use an old water color brush to spread it on things, and keep the paint where little kids can't get it."

At that moment, Mr. Morrow entered the dining room. "Hi, boys. Still on the track of the atom?"

"I'm getting some of this radium paint like you told me, Dad."

"Good. Scrape off as much of that yellowish stuff as you can. We're going to use it for our experiments in atomic energy."

"Boy, *I'm* not going to get near that stuff," Sam said. "A couple of the TV Rocket Rangers got mixed up with a radioactive asteroid once. They ended up in the Base Hospital."

"Maybe that asteriod gave off real powerful radiation," Randy said.

"I don't know—" Sam hesitated. "Maybe it's all right. That

stuff you're scraping off doesn't *look* radioactive. The asteroid that clobbered the TV Rocket Rangers buzzed and glowed."

Randy laughed. "Radioactive stuff doesn't buzz!"

"That's right," Mr. Morrow agreed. "One of the funny things about radioactive materials is that you can't detect them with the senses. If you had a piece of pure radium metal, you might not be able to tell it from a piece of silver just by looking at it, listening to it, smelling it, tasting it, or feeling it."

"I thought radium caused bad burns," Randy said.

"It does. And a piece of pure radium would be very dangerous. But you wouldn't know you were being burned if you touched it. A piece of radium would be a few degrees warmer than other objects in the room—but you'd scarcely notice it."

"Well, then—what causes the burn?" Sam wanted to know.

"The radiation," said Randy.

"Well, what *is* radiation? Sort of like a ray gun?"

Mr. Morrow said, "There are different kinds of radiation. We'll find out about them soon. But first we have to find a way to tell whether radiation is present or not."

Mr. Morrow pointed to the dish of paint scrapings. "Take this radium compound that Randy scraped off. We know it's radioactive because the notice on the clock face says 'radium dial.' But how could you prove it?"

"Get a geiger counter," Sam offered. "If it clicked, the stuff would be radioactive."

"That would be one way," Mr. Morrow agreed. "But we don't have a geiger counter. We'll have to find another way. A simple way, that doesn't take any special equipment. Any ideas, Randy?"

Randy thought a moment. "Radioactive stuff is supposed to fog photo film, isn't it?"

"Right! That was the way radioactivity was discovered back in the 19th century. Sam, how would you like to do an experiment?"

"Gee, yes!"

"First, find a shoe box. Then get some wide adhesive tape, a piece of clean shirt cardboard, a piece of aluminum foil, some scissors and some paper clips. Then get a roll of unexposed film out of my desk drawer, and bring my key chain with the big Mexican penny on it."

"I hope I can remember everything," Sam said, and dashed out of the room.

"Actually, Randy," his father went on, "all of our knowledge of radioactivity is based on the effect radioactive materials have on other substances—like the geiger tube or the piece of film. Nobody has ever *seen* radiation particles. Probably no one ever will. But we can detect the effects they produce."

By now, Randy had managed to scrape nearly all of the radioactive paint off the alarm clock dial. He set the saucer aside, covering it carefully with a piece of thick cardboard to keep the dust from blowing around the room.

"Dad, back at the sporting goods store you said that radioactivity was all around us. Why doesn't it hurt us?"

"Natural radioactivity is so weak that it seems to have very little effect on us. Take cosmic rays. Those are really powerful little particles of radiation that bombard the earth from outer space."

"Where do they come from?"

"Scientists aren't sure. We don't feel them, even though thousands of them strike our bodies each year. The particles of radiation may injure several cells in the body, but our

natural powers of healing repair the damage and we never even know that anything hit us."

Randy laughed. "I imagine that a few KO'd cells out of the billions we've got wouldn't make much of a dent."

Mr. Morrow agreed. "Radioactivity becomes dangerous when there are so many particles damaging cells so fast that the body can't keep up with the repairs. Or when the radioactive atoms themselves get into the body and become lodged someplace where they can continue to give off radiation particles for a long time."

"Is that what happened to Sam's TV Rocket Rangers?"

Mr. Morrow began to chuckle. "When we *do* travel into outer space, you can bet that our explorers will have more sense than to prance around on an asteroid without checking it first. As a matter of fact, a 'hot' asteroid would be a valuable piece of property. The prospectors of the future will probably search for radioactive asteroids just like the men of today hunt uranium ore on the Colorado Plateau."

"Is natural radiation good for anything?"

"The sun's light and heat come from atomic energy," Mr. Morrow said. "We probably don't get much in the way of subatomic particles from the sun, though."

"How about cosmic rays?"

"They *are* useful. In a very special way. Ever hear of the carbon-14 test?"

"Yes. Doesn't it help in figuring the age of very old organic objects?"

"Right. This is the way it works. Picture a cosmic ray particle coming into the earth's atmosphere. It has a lot of energy, and it hits the atoms of air that happen to be in its path. If it strikes a nitrogen atom, the nitrogen will never be the same again. It's *transmuted*—changed into another element: It turns into an atom of carbon-14. This is a radio-

active isotope of ordinary carbon."

"I see."

"A lot of these carbon-14 atoms are made. Now imagine a tree. You and I breathe oxygen, but a tree needs carbon dioxide to live. It takes in the gas and turns it into the cells that make up its leaves and trunk and roots. Some of the carbon dioxide that the tree takes in is going to contain 'hot' carbon-14 atoms that the cosmic rays made. As long as the tree lives and grows, it keeps accumulating this carbon. But when it's chopped down and dies, it stops taking in carbon-14."

"I get it," Randy said. "Maybe each year it would take in, say, 100 radioactive atoms. After 10 years it would have 1,000 of them."

"That's roughly true, although the number of radioactive atoms is much greater. As long as the tree is alive, the radiation it gives off stays at a certain level. But as time goes on, the atoms in the dead tree get less and less radioactive. In 5,600 years, half of the atoms of carbon-14 won't be radioactive any more."

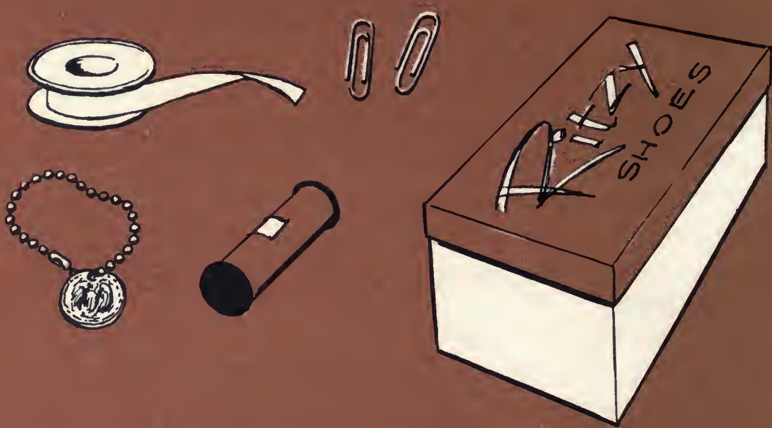
"You mean that carbon-14 has a half-life of 5,600 years," Randy said. "I've heard about half-life."

"The scientists measure the radioactivity in an ancient piece of wood. Then they can calculate how long ago the tree lived. The process works for cloth, seeds, paper—any plant products."

Randy frowned slightly. "And I'll bet that since animals eat plants, the radioactive carbon would get into their bodies, too."

"Right. Any substance that was once alive can have its carbon-14 measured. Scientists have used the test to calculate the age of Egyptian mummies, ancient corn found in Inca graves—even things like the Dead Sea Scrolls that

Sam's experiment with radioactivity and film



1 Gather a shoebox, some unexposed film, adhesive tape, paper clips, and a key ring.

were written on parchment made from animal skin."

"And all this from cosmic rays!" Randy said.

Just then, Sam burst back into the room, waving a shoe

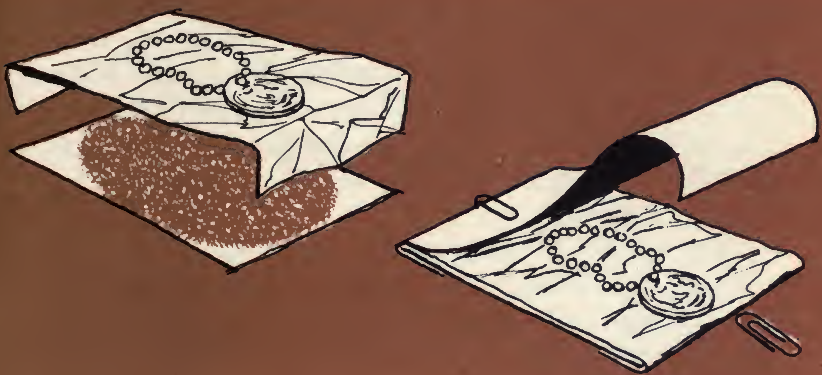
2 Cut out a four-inch square of cardboard, and a larger square of aluminum foil.

box that rattled.

"I've got the stuff you asked for, Dad! Now, what's the experiment?"

Mr. Morrow explained carefully. First, they cut out a 4-inch square of shirt cardboard and carefully spread a thin layer of Randy's radium paint dust over it, with a brush.

Then they covered the dusted side of the cardboard with a small square of aluminum foil, folded it under, and fas-



3 Spread radium paint on cardboard, cover with foil. Assemble other parts as shown, in total darkness, placing film glossy side down. Seal film pack in shoebox and keep in dark place for three or four days. Then develop film.

Turn to Chapter 2 to see the results of Sam's experiment.

tened the cardboard and foil together with a couple of paper clips.

"This is your source of radiation," Mr. Morrow explained. "We covered up the radioactive dust to keep it from spreading around. Aluminum stops some particles, but a lot of

radiation will come right through it. Now, lay the key chain with the coin on top of the foil."

They did so. Mr. Morrow picked up the roll of film and handed it to Sam.

"Sam, do you know where the next part of this experiment will be carried out?"

"Where?"

"In the darkest closet you can find."

"You're kidding, Dad," Sam said.

Mr. Morrow insisted he wasn't. "You take your shoe box in, with the photographic film and the radiation source. When you get inside, close the door tight and let your eyes get used to the dark a minute. You'll be able to see a little before long. Then open the package of film and unroll it. Cut off a piece big enough to go around the radiation source and the key ring. Fasten it tightly around the package with the paper clips."

"Then what?"

"Put the radioactive package into the shoe box and seal the lid on with adhesive tape. Then put the box in a dark place and leave it alone for about four days. We'll see what happens."

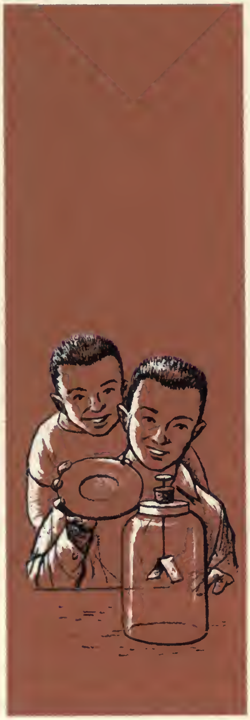
Sam streaked out of the room, heading for his bedroom closet.

"How about my experiment, Dad?" Randy asked.

"Coming up," Mr. Morrow said. "Let's go down to the workshop. We're going to make a radiation detector."

CHAPTER 3

Randy makes an electroscope



"I'M GOING to let you make this radiation detector yourself," Mr. Morrow said. "But first, I want you to know how it works."

"Okay, Dad, shoot."

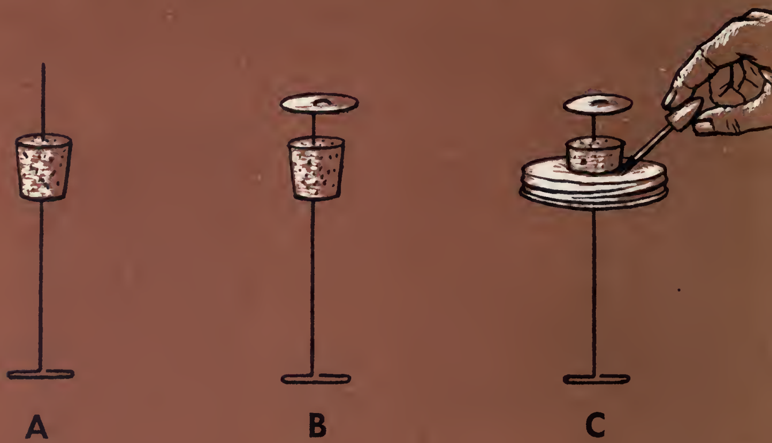
"Scientists know many ways to detect radiation. One of the ways it betrays its presence is by causing static electric charges to leak away. You know what static electricity is, don't you?"

"Sure. That's what makes hair stand on end when you comb it on a cold, dry morning."

"Right. And if you were combing your hair near a source of radiation, the hairs would tend to lie down much more quickly than they would otherwise."

"Why is that?"

How Randy made his aluminum-foil electroscope



Making the cap assembly

1 Cap assembly is made from jar lid, large cork, fine copper wire, disk of copper metal, and nail polish. Pierce cork with hatpin to make hole, then work copper wire through. Bend lower end into T-shape as in A. Punch two holes in copper disk, thread upper end of wire through them as in B. Fit cork assembly in hole cut in jar lid. Use nail polish to seal juncture of cork and lid as in C.

"The charge leaks into the air. Look at it this way. You know a static charge doesn't move. But if an electric conductor, like a wire, comes near the static charge, it's likely to flow into the wire."

"But air's an *insulator,* isn't it?"

"Not always. Air can be a conductor when it's damp or hot. Another way it can become a conductor is when some of the air atoms have their electrons knocked off by particles of radiation."

"Just like the gas in the geiger tube!" Randy exclaimed.

"Yes. The radiation ionizes the air it passes through, just

Attaching the foil and completing the electroscope

2 Remove thin aluminum foil from gum wrapper with alcohol. Cut two strips of foil about 1 inch long, one-half inch wide. Fasten them to T-arms with two dabs of nail polish. Heat cap assembly and clean jar in 250° oven for about five minutes to drive off moisture. Screw lid tightly on jar before it cools. Now the electroscope is finished.

like it ionized the gas."

Mr. Morrow went on to explain that the instrument Randy was going to build operated on the same principle as static-electrically charged hair. It would be charged up with static electricity. The speed with which the charge leaked away would indicate how strong a source of radioactivity was present.

"I'm making a list of things you'll need to make this radiation detector. You'll be able to find everything around the house."

"What's this instrument called, Dad?"

Charging the finished electroscope

3 Charge electroscope by any of these methods: 1) rub glass rod vigorously with silk scarf, touch rod to copper disk; 2) comb hair hard with rubber comb, touch comb to disk; 3) on dry day, shuffle feet as you stand on a heavy carpet holding a penny, then touch penny to disk. When electroscope is charged, leaves fly apart in V shape.

"An electroscope. There are several kinds. This is a foil electroscope."

Randy examined the list of materials while his father explained how the electroscope was to be put together.

"Seems simple enough," Randy remarked.

"It is—now that you know how to do it. But remember that this little gadget will show you that invisible particles are present—bits of matter too small to be seen under the most powerful microscope. But the electroscope proves they're there."

Rándy's father left the workroom, and the boy began to

collect the items on the list:

Pickle jar (quart size)
Jar cap
Large cork stopper
Hatpin
Thin copper wire
Small sheet of thin copper metal
Clear nail polish
Foil chewing gum wrapper

First, Randy cleaned the pickle jar and cap thoroughly with detergent and set them aside to dry. He knew that the jar would have to be absolutely free of dampness or the experiment would fail.

Next, he cut off a piece of copper wire about 7 inches long. He bent one end so that it formed a crossbar like the head of a T, with the arms about one-half inch wide. Then, taking the cork, he carefully pushed the hatpin lengthwise through the center of the cork, then removed the pin and thrust the free end of the copper wire through the hole he'd made. He left about an inch protruding from the top of the cork.

Using a pair of tin snips, he cut a circle an inch or so in diameter from the sheet of copper metal. He sandpapered it until it was shiny, then poked two small holes in its center, like those in a button. He fastened the upper end of the wire and cork assembly onto the copper disk by threading the wire through the holes, then bending the wire until the disk was firm and horizontal.

The thing now looked like a tall, thin nail with a T-shaped bottom, thrust through a cork.

The next step was to punch a hole, slightly smaller than the widest part of the cork, through the top of the jar lid. The idea was to put the cork and wire assembly through

Testing radioactivity's penetrating power

4 The charge on the electroscope will drain off when the device is placed near a source of radioactivity. This happens because radiation particles ionize air molecules and make them electrical conductors. Place barriers of various types of material between radiation source and electroscope to test penetrating power of rays. Try paper, aluminum foil, toothpaste-tube metal, plastic, and piece of crystal glassware. Do some of these materials let more radiation through than others?

this hole, plugging it up. Randy found the T-shaped end of the wire slightly too wide to go through the hole in the lid; but a little bending fixed that.

When the cork was firmly seated in the hole, Randy dripped a quantity of the clear nail polish around the place where the cork met the jar lid, to make a tight seal. He also painted the top of the cork where the wire ran through.

His next job was to separate the thin aluminum foil on the gum wrapper from its wax paper backing. His father had warned him the ordinary kitchen aluminum foil would be too heavy. After trying without success to pry it off with his finger nails, he tried to dissolve the glue that held it on. Rubbing alcohol finally did the trick.

He cut two strips from the foil, each about one-half inch wide and an inch long. He attached them to the arms of the T with a tiny dab of nail polish.

Then he took the electroscope into the kitchen and placed it in the oven with its lid ajar. He heated it at a temperature of about 250° for a few minutes to drive out any moisture that might remain, then screwed the cover on tightly.

"Dad!" he called. "It's all done!" Randy stepped into the dining room.

"What's done?" asked Sam curiously. He was sitting in the middle of the floor, surrounded by a huge stack of comic books. He had discovered them in the back of the closet when he was finishing his experiment.

Randy explained, "I just made this electroscope. Hi, Dad. How's this?"

Mr. Morrow came in and examined the jar. "Looks pretty good. Let's try it out."

"Want me to comb my hair to get a spark?" Randy suggested.

Mr. Morrow laughed. "That crew-cut isn't good for much of a charge. Rubbing a glass rod with silk will give us static electricity, too. Sam, you get one of your mother's silk scarves. Randy, see if you can find a glass stirring rod."

When the items were located, Mr. Morrow told Randy to rub the glass rod firmly with the silk, then touch the rod to the copper disk on top of the electroscope.

Randy rubbed faster and faster. The silk began to crackle.

Carefully, Randy brought the rod close to the copper disk, then touched it.

There was a tiny spark. The small strips of foil sprang apart and stood out stiffly like an upside-down V.

"Now touch the copper disk with your finger," said Mr. Morrow. The aluminum strips began to come together, finally, they hung straight down once more.

"Your finger acted as a conductor, leading the electricity out of the jar and down to the floor. Now watch what happens when I hold a match near the disk. Charge it again, please."

The foil leaves, which had sprung apart again when charged, collapsed instantly.

Mr. Morrow said, "Heating air makes it a good conductor of electricity."

"I want to try my radium paint," Randy said. He gathered the powder into a pile in the center of the saucer, charged the electroscope, and tilted the saucer up toward the copper disk. The leaves began to collapse slowly.

"You'll want to try putting some barriers between your radiation source and the electroscope," Mr. Morrow said. "See which substances absorb radiation, and which let it through."

"What d'you think I ought to try, Dad?"

"Paper, tin can metal, toothpaste tube metal, thicker aluminum foil, plastic. Then try one of your mother's cut-glass goblets—and for heaven's sake don't drop it. You'll find that the glass absorbs nearly all the radiation. That's because it has lead in it."

Randy said, "They use lead shields to screen off reactors, don't they?"

"They used to use it a lot—actually, most modern shielding is made of reinforced concrete. It's cheaper and stronger

—even if you do have to use more of it."

"I suppose that the heavier and thicker a material is, the more radiation it'll absorb."

Mr. Morrow said, "In general, that's true. Of course, some kinds of radiation have less penetrating power than other kinds."

Sam exclaimed, "Yeah, how about the different kinds of radiation? The Rocket Rangers' radioactive asteroid was full of gamma rays and neutrons!"

"We can understand them better if we make some models of the atom. Tell you what. My friend Earl Wood is coming over tomorrow evening. Maybe I can talk him into explaining the nucleus for us."

"That'd be great, Dad," Randy said.

"Me, too!" said Sam excitedly. Suddenly his face fell. "But, Dad—"

"What is it, Sam?"

"Can we wait until after seven o'clock? I *can't* miss the Rocket Rangers! Tomorrow they face the fish-men from Neptune!"

CHAPTER 4

Secrets of the nucleus

"I HAVEN'T messed around with modeling clay since I was a little kid," Randy's brother Sam remarked.

He took a blob of green clay, rolled it into a thin cylinder, and converted it into a rattlesnake coiled to strike.

"I've got a hot flash for you," Randy said. "You're *still* a little kid. Quit fooling around and get back to rolling that stuff into little balls. We're making atoms tonight—not a snake-charming act."

The boys sat at the kitchen table. Before them was a box of modeling clay in various colors, and a container of toothpicks. Randy was making a stack of blue balls about one-half inch in diameter. Sam was supposed to be making some red balls the same size.

"My stack is nearly twice as big as yours," Randy said

disgustedly. "Get going. We've got to have these ready by the time Dad and Mr. Wood come in."

"I'm almost finished," Sam muttered.

The boys heard adult voices approaching. Dad and Mr. Wood came into the kitchen, took four bottles of cola out of the refrigerator, and sat down at the table with Randy and Sam.

"You boys know Mr. Wood," said their father.

"You bet," Randy said. "Hi, Mr. Wood."

"Greetings, men." The scientist took a gulp of cola. "Got those clay balls all finished?" Wood was a tall, thin man with a crop of crew-cut blond hair. He was a scientist at the Argonne National Laboratory.

Randy gathered up his and Sam's clay balls and placed them in front of Mr. Wood. "Here they are. Just like Dad told us to make 'em."

"Okay, let's build some atoms."

Mr. Wood took a single red ball, marked a plus sign on it, and stuck it onto the end of a toothpick.

"This ball represents the nucleus of the simplest kind of atom," he said, working up a blob of white clay into a base for the toothpick to stand in. "I'm marking the letter *H* on the base of this model. Know why?"

"H is the symbol for the element hydrogen," said Randy.

"Right. And hydrogen is the simplest element. Most of the hydrogen in the universe has just one particle in its nucleus. If we wanted to make this model complete, we'd add the electron that whirls around the nucleus."

"How far away would we have to put the electron to make this a scale model?" Mr. Morrow asked.

"Well, this nucleus is about one-half inch in diameter. Scientists know that the nucleus takes up only a small part of the space within the atom. To make this model to scale,

the electron would have to be nearly a mile away!"

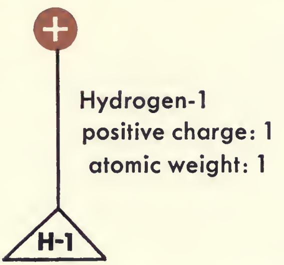
"Wow!" said Sam.

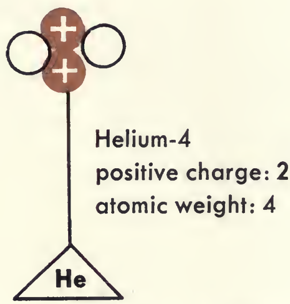
Randy said, "So that's what they mean when they say that atoms are mostly empty space!"

"We won't worry about the electrons tonight. Atomic scientists deal mostly with the nucleus. So let's try to unravel a few of the secrets of the nucleus."

Mr. Wood set the model of the hydrogen nucleus in the center of the table.

"So here we have a hydrogen nucleus. It weighs something. On the scale of atomic weights, it has a mass of about one unit. It also carries a charge of electricity. I've represented that by the plus sign on the clay ball, since the charge is *positive*."





Mr. Wood took up another red clay ball and marked a plus on it. "The hydrogen nucleus has another name. We call it a *proton*, and it's one of the main building blocks of atomic nuclei. All elements have one or more protons in their nuclei. In fact, it's the number of protons in the nucleus that determines the identity of the element."

"Suppose you started building atoms," Randy said. "You mean that the lightest atom has one proton, the next lightest kind has two protons, and so on up the line?"

"You've got the right idea, Randy. Hydrogen has one,

helium two, lithium three, beryllium four—and so on through the entire table of elements. Uranium has 92, and nobelium has 102."

Sam exclaimed, "I'm gonna build a helium nucleus!"

He took two protons, stuck them together, and mounted them on a toothpick stand. "There! Helium! Atoms are easy to understand!"

Randy said, "How about it, Mr. Wood? Does a helium nucleus really look like that?"

"I'm sorry, Sam." Mr. Wood explained that while Sam's helium nucleus had the right number of positive charges, it was not heavy enough. By actually weighing atoms of helium, scientists had found that their atomic weight was *four*—not two.

"But we can't put in four protons," Sam argued. "That would give us too many positive charges."

"You're absolutely right, Sam. We need another kind of nuclear building block. Something that will add atomic weight without increasing the number of positive charges."

The scientist picked up a ball of blue clay. "Gentlemen, meet the neutron!" He stuck two of the blue balls to Sam's model helium nucleus. It now had two red balls and two blue ones.

"Neutrons also have an atomic weight of one, but they have no positive charge."

"I see," Randy said. "So when you add the two neutrons to the two protons in the helium nucleus, you get an atomic weight of four just like you're supposed to—but there are still only two positive charges."

"Bullseye," smiled Mr. Wood.

He went on to say that all atomic nuclei are made up of protons and neutrons in different combinations.

"You know that two positive charges would tend to repel

each other. Well, it seems that the neutrons have a sort of stabilizing influence on the protons—it's as though they diluted the positive charges so that the protons were able to stay together."

"If the neutrons weren't there, I suppose the nucleus would break apart," Randy observed.

"It certainly would. As a matter of fact, most of the lighter atoms have nearly the same number of protons as neutrons in their nuclei. But as the nucleus gets larger in heavy atoms, it seems that more neutrons are needed to keep the protons from flying apart. Barium, for example, has 56 protons and 81 neutrons. The heavier the element, the more neutrons there are in relation to the protons."

"How about uranium?" Sam asked.

"It has 92 protons and 146 neutrons. But in the case of all elements heavier than bismuth, with 83 protons, the nucleus doesn't seem to be able to stick together no matter *how* many neutrons are in it. These heavy atoms like radium and thorium and uranium come apart at the seams. Little pieces of the nucleus keep breaking off until the nucleus shakes down to 82 or 83 protons."

"What's element 82?" Sam asked.

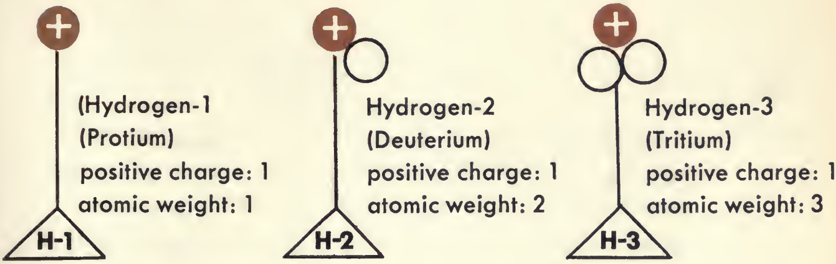
"Lead," said the boy's father. "All natural radioactive elements eventually turn to lead. Some artificially created heavy elements end up as bismuth."

"And this breaking up of the nucleus—" Randy put in. "This is radioactivity, isn't it?"

"Yes. Actually, *any* rearrangement of the particles within the nucleus—whether any pieces get tossed out or not—produces what we call radioactivity. Let's build a simple radioactive element and see what goes on inside it."

Mr. Wood took a proton and mounted it on a toothpick stand. "Here we have ordinary hydrogen."

Isotopes of hydrogen



The isotopes of hydrogen have the same number of protons in their nuclei, but different numbers of neutrons. Isotopes of an element have the same positive charge, but different atomic weights.

He added a blue ball. "Adding this neutron gives us heavy hydrogen, what we call an *isotope* of the ordinary form of the element. Isotopes have the same number of protons in their nuclei, but different numbers of neutrons."

He added still another neutron to the model. "Hydrogen-2 is still stable. But when I add another neutron to make hydrogen-3, we've got a nucleus with too many neutrons. What do you think happens to hydrogen-3, Randy?"

"I suppose it would readjust itself somehow."

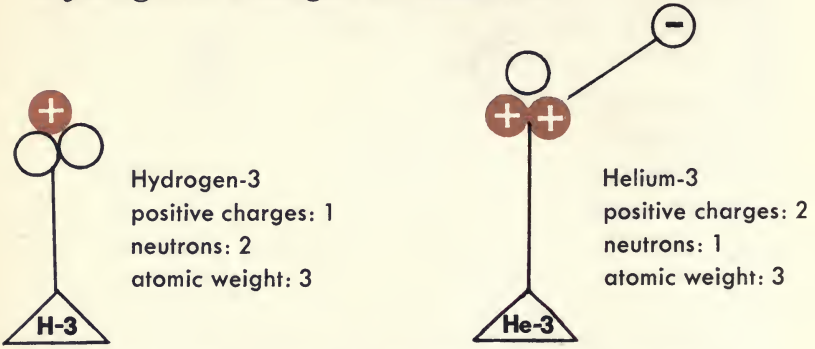
Sam said eagerly, "I bet hydrogen-3 is radioactive!"

"Both of you boys are right," Mr. Wood said. "The nucleus of hydrogen-3 changes. It throws off an electron—which we can think of as a negative charge without much mass—and one of its neutrons changes into a proton!"

Sam's face fell. "But how could that be? A neutron hasn't got any charge at all! If it's going to change into a proton, it's got to get a positive charge from *somewhere*. And where did the electron come from?"

Wood laughed. "Sam, I wish I could give you answers

Hydrogen-3 changes to helium-3



Hydrogen-3 is an unstable nucleus with too many neutrons. It stabilizes itself by throwing off a negative beta particle (electron). One neutron changes to a proton, and the nucleus becomes helium-3. The process is called radioactive disintegration or decay.

to those questions. Atomic scientists just don't know exactly how neutrons are able to change into protons. They do it. But we don't know *how* they do it. The fact is, unstable nuclei with too many neutrons usually throw off an electron in just this way."

He replaced one of the neutrons in the hydrogen-3 nucleus with a proton. A green ball on the end of a toothpick was stuck into the proton to represent the electron being thrown off.

"Now you can see that our nucleus has changed. Since the number of protons in the nucleus is what determines the kind of element we have—"

Randy broke in, "This isn't hydrogen any more!"

"Right. It's helium."

Randy brought forward the model of the helium nucleus that Sam had made. "But this helium nucleus we made be-

fore has *two* neutrons in it. The new one has only *one*."

"Helium-3 and helium-4 are isotopes. Just like the three isotopes of hydrogen with weights of 1, 2, and 3. Most elements have several isotopes. Unstable isotopes are called radioisotopes. There are hundreds of isotopes known today."

Mr. Morrow said, "How about showing us some other ways that atoms can be radioactive?"

"All right," Mr. Wood agreed. "We've seen what happens when a nucleus has too many neutrons. Now let's take a nucleus with too many *protons*."

He fashioned a nucleus of carbon, an element with six protons. Then he added five neutrons.

"This is a nucleus of carbon-11. It's very unstable because it has too many protons. In this case, one of the protons is going to give off its positive charge and change into a neutron!"

He replaced the red proton with a blue neutron. A tiny red ball of clay on the end of a toothpick was stuck into the neutron to represent a positive charge being thrown off.

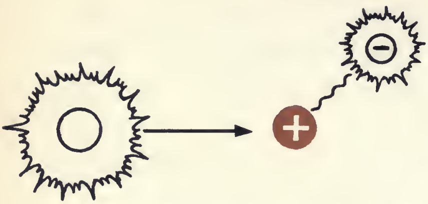
"The nucleus tosses out a positive charge. This is really a positive electron known as a positron. It also has very little mass."

Randy said, "Isn't this reaction pretty much the same as the first one? Except that the charge thrown off is positive instead of negative."

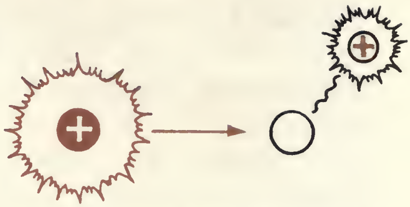
"You're right, Randy. The kinds of radioactivity are very similar. In both cases a type of electron is thrown off. We call these electrons that are thrown off from the nucleus *beta particles*. The first kind of radioactivity is negative beta-activity. The second kind is positive beta-activity."

Sam picked up the model of the carbon nucleus. "Now

How neutrons and protons change



1 Negative beta activity. A neutron changes into a proton by throwing off a negative beta particle (electron).



2 Positive beta activity. A proton changes into a neutron by throwing off a positive beta particle (positron).

that one of these protons has been changed into a neutron, I suppose this isn't carbon anymore."

Mr. Wood agreed with him. "Now that we have only five protons in the nucleus, this is an atom of an element called boron. This is boron-11. Five protons, six neutrons."

Suddenly Randy pushed back his chair and stood up. "Mr. Wood! I've got it! I've figured out how neutrons and protons can change into each other!"

Mr. Wood looked surprised. "Well, great! How?"

Randy quickly rolled up a white clay ball. On its surface he stuck a tiny green ball and a tiny red ball.

"These colored balls are supposed to be beta particles. The green one is negative and the red one is positive. Got it?"

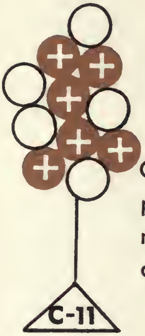
"Got it!" chorused Sam, Mr. Morrow, and Mr. Wood.

"Okay. This white ball with the charges on it—call it a *glarf*."

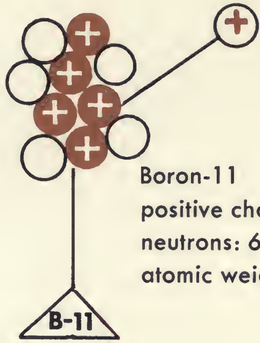
"Glarf?" Mr. Wood looked startled.

Randy said hastily, "Just a name I made up. This glarf is supposed to represent a mass of one. The two colored balls

Carbon-11 changes to boron-11



Carbon-11
positive charges: 6
neutrons: 5
atomic weight: 11



Boron-11
positive charges: 5
neutrons: 6
atomic weight: 11

Carbon-11 is an unstable nucleus with too many protons. It stabilizes itself by throwing off a positive beta particle (positron). One proton changes to a neutron, and the nucleus become boron-11.

represent an electric charge. Now this first glarf has positive *and* negative charges. They cancel each other out, so the glarf is electrically neutral. It's a neutron!"

Randy removed the green negative charge. "We toss off a negative particle—presto! Our glarf is left with a positive charge and it's a proton!"

Randy next removed the red positive charge. "If a positive charge gets thrown off, what's left is the bare glarf! Electrically neutral!"

Mr. Wood said, "What you're really proposing, Randy, is that there are two kinds of neutrons. A type that can throw off beta particles and a type that doesn't—your glarf."

"Right! How does that strike you?"

"It's very ingenious, Randy, although there are several important mathematical objections to it. If you decide to become an atomic scientist, you could study wave mechanics and nuclear particles. You might even discover your glarf!"

"Funny thing about your glarf," Mr. Morrow mused. "If the theory had something to it, there should be a type of particle with a mass of 1 and a negative charge."

Mr. Wood nodded. "A negative proton."

Mr. Morrow went on, "And they've discovered one negative proton!"

"Whoopee!" said Randy.

"Not so fast. It's very rare. We don't know much about it. It certainly isn't a common nuclear building block."

"These beta particles," Sam said. "Are they the only things that get thrown out of the nucleus?"

"No, Sam. Heavy radioactive elements like radium and uranium—plus a few lighter elements—throw off radiation called alpha particles. Incidentally, alpha and beta are the first two letters of the Greek alphabet. Gamma is the third letter. Alpha particles are ordinary helium nuclei. Two protons and two neutrons."

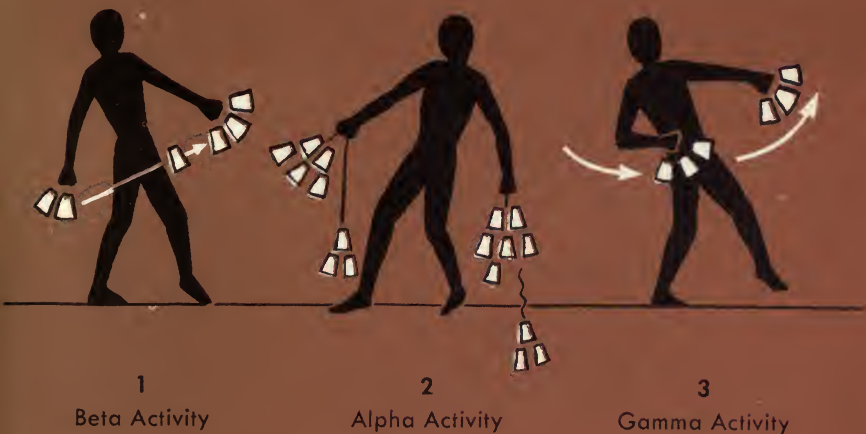
"You mean, the radioactive nucleus throws off this whole bunch of particles? Not just separate protons or neutrons?"

"The alpha particle seems to be a very stable combination. When the nucleus of an unstable heavy atom is readjusting itself, it seems to want to shake itself down quickly. So instead of tossing out single protons or neutrons, it tosses out the whole alpha particle."

Mr. Morrow said, "How about using this as an example. A man is balancing on a tightrope. In each arm, he carries a number of weights. Now if he loses his balance, he might toss the weights from one arm to another and stabilize himself. This would correspond to the juggling of charges that takes place during beta activity.

"Notice that the man doesn't drop any of the weights. He just shifts them. In the same way, the beta-active nucleus doesn't lose more than a tiny fraction of its mass.

How unstable atoms restore their balance



The man on the tightrope carrying weights represents an atomic nucleus with its particles—protons and neutrons. If the man loses his balance, he may do one of three things to restore his balance. 1) Juggle the weights from one arm to another. 2) Drop a group of weights. 3) Move the weights in one arm closer to or farther away from his body. These movements can be compared to the three common types of radioactivity, means by which atomic nuclei restore their own balance between protons and neutrons.

"But now suppose that our tightrope walker is loaded down with weights. If he loses his balance, he might *drop a few,* rather than shifting them. Some of the weights might be tied together in a bunch. So the bunch would be dropped."

"And the bunch of weights corresponds to the alpha particle?"

"Right," said the boys' father.

"Are there any other kinds of particles that come out of

Gamma rays are similar to x-rays

1 X-rays are formed when electrons outside the nucleus move up and down in various energy levels.

2 Gamma rays are formed when particles in the nucleus move up and down in energy levels of their own.

the nucleus?" asked Sam.

"Neutrons come out when the nucleus is split," Mr. Wood said. "They can also be produced when some elements are bombarded by radiation. Then there are less common reactions that produce protons, deuterons, and tritons.

"Not until I become an atomic scientist," laughed Randy.

"I suppose gamma rays are another kind of particle," Sam remarked. "The TV Rocket Rangers landed on a radioactive asteroid that gave off dangerous gamma rays."

"Gamma rays *can* be very dangerous," Mr. Wood agreed. "However, they aren't made up of particles. They're related to light waves and x-rays. X-rays are made when the electrons outside the nucleus move up and down in various energy levels. Gamma rays are probably made when particles *inside* the nucleus move up and down in energy levels of their own. Most of the time—maybe all of the time—gamma rays accompany nuclear changes. Sometimes no parti-

cles at all are given off. But we still know things are happening within the nucleus because of the gamma radiation given off."

"Take my man on the tightrope again," Mr. Morrow said. "In this case, he'd simply heft the weights in one arm to stabilize himself. Maybe by clutching the weights closer to his body."

Mr. Wood gulped down the remains of his bottle of cola. "It's getting late, so I'll have to take off now. I hope the mysterious nucleus is a little less mysterious!"

Randy and Sam laughed. "A little, Mr. Wood."

"Tell you what, boys. You come over to my place tomorrow after dinner. I have some photos of the tracks atomic particles make. They'll interest you."

"Thanks a lot, Mr. Wood," Randy said. "We'll be there —bright-eyed and bushy-tailed!"

CHAPTER 5

Pieces of atoms

RANDY and Sam stepped out of the elevator that had brought them up to the Wood apartment.

"What kind of a place do you suppose an atomic scientist would have?" Randy wondered.

Sam said he didn't know. "Wonder if he ever brings any 'hot' atoms home with him?"

"He sure doesn't," Randy said emphatically. "And don't go asking any questions like that or we'll both get bounced out."

They rang the apartment bell and a pretty red-haired woman came to the door. "Won't you come in, boys?" she invited. "I'm Mrs. Wood."

Mrs. Wood explained that her husband was on the phone. She invited Randy and Sam to wait in the study.

"The place looks just like *anybody's* home," said Sam in a hoarse whisper. He looked disappointed.

"Did you expect an atom-smasher in the living room?"

Randy began to prowl around Mr. Wood's little study. The walls of the room were almost completely covered by bookshelves. "Look at these book titles," Randy said. *"The Structure of Matter. Thermal Power from Nuclear Reactors. Neutron Cross Sections. Reactor Handbook."*

"Being an atomic scientist must take a lot of brains," Sam said.

"You need a few brains," said Mr. Wood from the doorway. "But most of the time you just work hard."

"Oh, hello, Mr. Wood," said Randy. He sheepishly began to put back a book he'd removed from the shelf.

"Look over anything you like, Randy. What's that you've got there? *Sourcebook on Atomic Energy?* That's a very good book. It's full of basic information on atomic energy. I think you might get a lot out of it, although some parts might be a little deep."

"How about me?" Sam wanted to know.

"You might find it a little tough sledding," Mr. Wood said. "Once you get a bit of high-school mathematics, though, you'd find it much easier to understand."

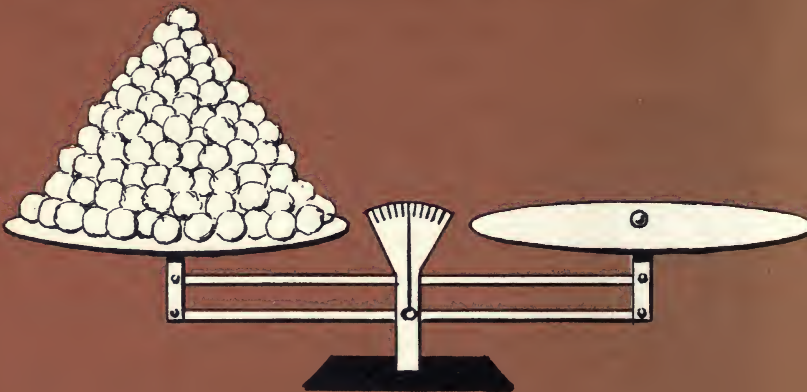
"You need lots of math for atomic physics, then?" asked Randy.

"Yes, you do," Mr. Wood agreed. "It doesn't take math to observe the effects of atomic energy. But math is the atomic scientist's main tool for explaining *why* nuclei and their particles behave the way they do. It lets you predict the way the particles will act."

"Wow," said Sam.

"Even though you'll never be able to see what you're working with, your equations and your slide rule make it

1,840 electrons weigh as much as one proton



Even though a proton is only two-fifths the size of an electron, it weighs 1,840 times as much. The proton could be compared to a heavy ball-bearing, while the electrons somewhat resemble cotton balls.

possible for you to visualize what's going on."

Randy thought a moment. "You could almost call math another sense. Like seeing or hearing. You can't see or feel nuclear changes. But you know how things are progressing through math."

Mr. Wood agreed. Then he told the boys that he'd like to show how atomic scientists are able to identify the particles thrown out of the nucleus.

The scientist stepped to a metal filing cabinet. "While I get some photographs out of my file, give me a quick rehash of the kinds of particles you know."

"There's protons and neutrons," Randy said. "They both have an atomic weight of just about one. The proton has a single positive charge. The neutron has no charge."

Sam said, "Then there's electrons—woops!—I mean beta particles. Regular electron-type beta particles have one negative charge. Positrons have one positive charge. I forget whether they weigh anything."

"Beta particles do have weight," Mr. Wood said, "but it's very small compared to that of a proton. It would take 1,840 electrons to weigh as much as one proton."

"They must be pretty small, then," Randy said.

"I've got a surprise for you. Electrons are *bigger* than protons or neutrons!"

"What? But last night—"

Mr. Wood frowned. "I'm afraid my models might have confused you a little. A proton is only about two-fifths the size of an electron, even though the electron weighs next to nothing. Maybe we could have given a more accurate representation by making our electron models out of big balls of cotton."

Randy's face fell. "Gee, that knocks my glarf particle on the head, doesn't it. How can a big thing like an electron be squeezed down so that it would fit inside my glarf?"

"That's one of the mathematical objections to your theory. The fact is, scientists just don't know how beta particles can be contained in the nucleus."

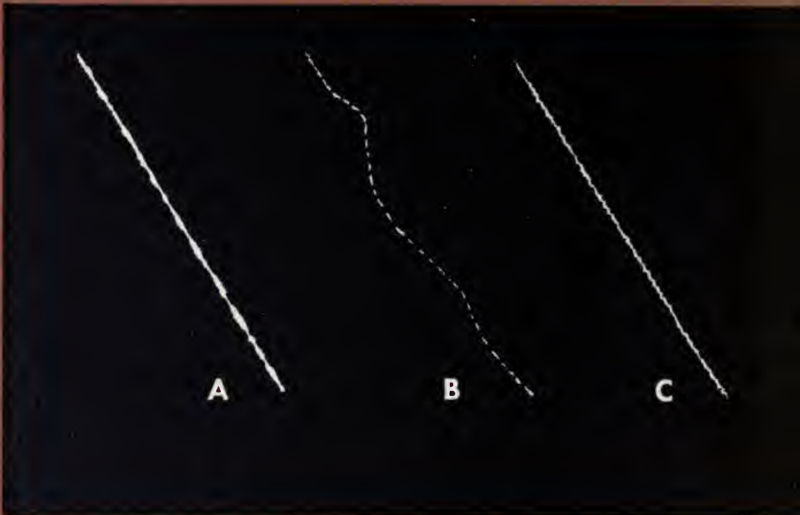
Mr. Wood brought out a stack of large, glossy photographs. "Proton, neutron, electron, positron. Are those all the particles you know, boys?"

"Alpha particles," Randy added.

"Doo— doo—" Sam struggled.

"Deuterons," Mr. Wood laughed. "A deuteron is the nucleus of an atom of hydrogen-2, It makes a good bullet for the nucleus. Tritons, the nuclei of hydrogen-3, are other particles. There are more kinds, but we needn't be concerned with them now."

The tracks made by radioactivity



Different kinds of radioactivity make distinctive tracks in a cloud chamber. A is the thick track of an alpha particle; B is the thin, wandering track of a beta; C is the straight, wavery track of a gamma ray.

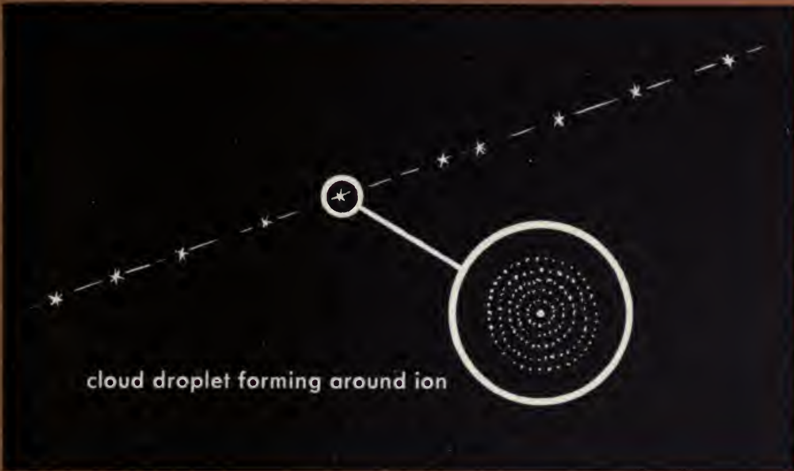
Mr. Wood picked up the first photo.

"These are photos taken of a device designed to make the tracks of nuclear particles visible. The thing is called a Wilson cloud chamber. It was named for the British physicist who invented it in 1911."

The boys crowded close. The background of the photo was black with a few tiny white specks. At the bottom of the photo was an object like a box. Radiating out from it like the ribs in a fan were thin white streaks.

"The box has a tiny opening in its side," Mr. Wood said. "It holds a sample of the radioactive element polonium.

What makes ions in a cloud chamber?



A radiation particle moving through a cloud chamber collides with atoms of air and water molecules, knocking off electrons. The ions thus formed tend to attract water molecules, which condense about the ion in layers. The cloud droplet that forms around the ion is large enough to be seen.

Polonium gives off alpha particles."

"You mean the alpha particles made these streaks?" asked Randy.

"Yes. When they speed out of the piece of polonium into the cloud chamber, they collide with atoms of the molecules of air and water vapor that fill the chamber. Some of the electrons from the water molecules are knocked off, forming ions. Particles of vapor tend to condense on the ions, forming tiny cloud droplets."

Randy peered closely at the photo. "Each cloud track is made up of a trail of tiny drops."

Cloud tracks of positrons and electrons

Some nuclear reactions produce pairs of positrons and electrons. Here are the tracks of two pairs as they would appear in a magnetic field. The two positrons curve toward the negative pole, the electrons toward the positive pole.

"And you'll notice that many of the tracks have a kind of hook on the end. As the alpha particle loses its energy, it's apt to collide with the nucleus of some atom. When an alpha particle hits a nucleus, it bounces and changes its path."

Mr. Wood explained that the energy of the particle could be estimated by the length of the track and its density. If the chamber had a magnetic field, particles with an electric charge would tend to curve toward one pole of the magnet or the other.

"Here's a photo showing the tracks of a positron and an electron. The pair of them were produced by the action of cosmic rays on matter."

Mr. Wood showed them a photo of a beta-particle track. "This beta particle came from an isotope of radium. See how

Cloud track of a cosmic ray

This particle from outer space entered from the right. The star at the end of its track was formed when the cosmic ray particle struck an atomic nucleus and smashed it into fragments.

faint its path is, and how it curves because of the magnetic field."

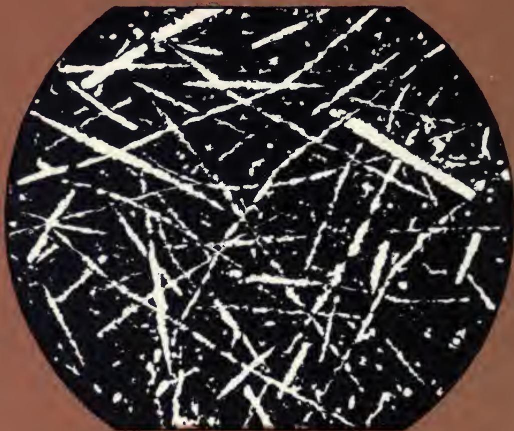
They also looked at cloud tracks made by gamma rays. Mr. Wood explained that gamma rays could cause ionization just as particles did.

"Suppose you had some radioactive stuff that was giving off all kinds of particles," Sam said. "How do you tell 'em apart?"

"You ought to be able to figure that out from what I've told you. How about it, Randy?"

"Well, I'd get a cloud chamber with a magnetic field, and put the radioactive stuff inside. The positively charged particles would go toward the negative pole of the magnet, and the electrons—I mean the negative beta particles—

Studying neutrons with a cloud chamber



Neutrons do not make ion trails by themselves. But if a cloud chamber is filled with hydrogen, the neutrons collide with hydrogen nuclei (protons), and the protons make cloud tracks.

would go toward the positive pole. I don't think gamma rays would curve at all."

"No, they wouldn't," Mr. Wood agreed. "Now if you were studying cosmic rays, you'd have to identify other kinds of particles. Look at this photo."

The boys looked over a photo in which a particle entered from one side and appeared to explode into several fragments, leaving a star-shaped trace.

"Here's where a powerful cosmic ray entered. It collided with a nucleus, and the nucleus shot off several different particles. There are protons, mesons, and other nuclear debris here. They can be identified by the amount of ionization they produced."

Randy asked. "Would a neutron make a track in a cloud chamber?"

"No. Neutrons don't knock off many electrons when they travel, so they wouldn't form enough ions. If you don't have ions, you don't have cloud tracks."

The scientist produced another picture. "But here's a way we can study neutrons through the cloud chamber. This chamber was filled with hydrogen gas and a beam of neutrons was passed through it. The neutrons collide with the protons of the hydrogen, and the *protons* make cloud tracks. We can tell things about the neutrons from the way the protons behave.

"Sort of like an invisible billiard ball rolling across a table filled with other balls?" Randy asked.

"That's not a bad simile. The invisible ball—the neutron—would knock the other balls aside as it passed. Mathematics would let you calculate the behavior of the neutron."

"Sharp," said Sam.

"I'm going to tell you how to make a cloud chamber of your own," announced Mr. Wood.

"Swell!" both boys exclaimed. Randy added cautiously, "It won't be expensive, will it?"

"Not at all. You've got most of the parts lying around your house. I've something else around here—"

He rummaged in a desk drawer and finally came up with a typed list of instructions and a diagram.

"Here's something else you can take with you. This is something I worked up for my sister's boy last year. He's a high school junior. It's the instructions for making a homemade geiger counter."

"Gee whiz!" exclaimed Sam.

"I want to tell you that the geiger counter would require an investment of about ten dollars for parts, though," Mr.

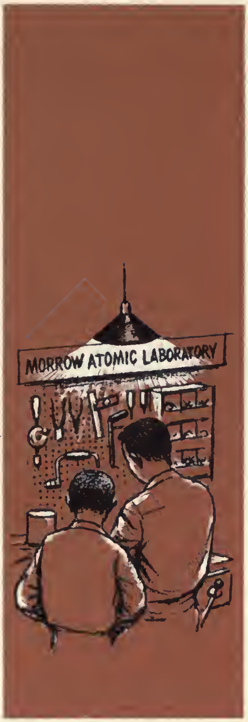
Wood warned. He grinned and said, "But maybe if your father really wants to encourage you, he'll float a loan to the Morrow Atomic Laboratory."

"I sure hope so," Randy said. "Thanks a lot, Mr. Wood."

"Not at all. Here's the instructions for the cloud chamber. Let me know how it comes out!"

CHAPTER 6

Randy makes a cloud chamber



THE WORKBENCH in the Morrow Atomic Laboratory was covered with books and pieces of Randy's model cloud chamber, which was under construction.

"Dry ice," Randy muttered, looking at the list of instructions Mr. Wood had given him. "Where am I going to get any dry ice?"

Randy's mother, removing clothes from the drier in another part of the basement, heard her son. She said, "Why don't you ask Mr. Carlson, down at the drugstore? I think he gets his ice cream packed in cartons with dry ice."

"That's a good idea. Thanks, Mom."

Randy ran upstairs, "Sam!" he shouted. His brother's head popped out of the kitchen. A huge oatmeal cookie was stuffed in Sam's mouth. He held a glass of orange

How Randy made his cloud chamber

1 A disk of black woolen cloth is cemented to the inner lid of a pint jar. Don't cover sealing ring.

2 Inch-wide strips of thick cloth are cemented to inside top and bottom of jar.

soda, still fizzing from sudden contact with ice cubes.

"Eating again," said Randy in disgust. "I need your help, Apprentice Technician Morrow. We've got to have dry ice for our cloud chamber."

Quick as a wink, Sam whipped the dish towel off the rack and tossed it to Randy. Then he pulled an ice cube out of his glass of orange soda and held it out. "Be my guest," he bowed.

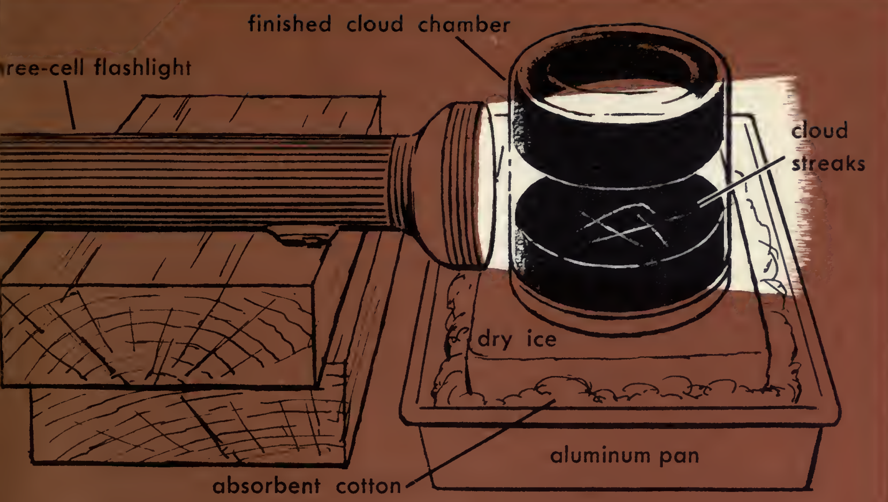
Randy growled and flicked him with the towel.

"Ow!" said Sam. "No sense of humor, eh, doc?"

"You know the kind of dry ice I mean. Zoom out to the drug store and ask Mr. Carlson for some."

"After I finish my pop."

"If you want to see the cloud chamber, you'd better get



3 The cloth strips and disk are saturated with wood alcohol. *This substance is poison; do not inhale fumes!* Screw lid tightly on jar, invert. Place jar, lid down, on cake of dry ice. Aim beam from three-cell (or more) flashlight into cloud chamber. Darken room. Watch for cloud streaks.

moving," Randy said darkly. He returned to the basement.

Once more, Randy checked his list of materials against the material he'd assembled.

Wide-mouth pint jar
Screw cover (with rubber seal)
3-inch disk of black woolen cloth
1-inch wide strip of thick cloth (any color), 2 feet long
Shallow metal pan
Large flashlight
Absorbent cotton
Rubber cement
Wood alcohol
Dry ice (about 4 inches square)

Randy began by cementing the cloth disk to the inside of

the jar lid. He was careful not to cover the rubber sealing ring, however.

Then he cut two pieces of thick cloth stripping. One he cemented around the bottom of the inside of the jar, forming a felt ring extending up the sides. The other strip was cemented around the inside of the mouth of the jar, just at the rim.

He set up the flashlight, aiming it horizontally. A layer of absorbent cotton was placed in the shallow metal pan.

"Now if that Sam only gets here with the dry ice, we're in business."

Randy's mother came over to inspect the cloud chamber. "This isn't going to make any mess, is it?"

"No, Mom. Everything happens inside the jar. You can watch it, if you like."

Sam came clomping down the stairs. He carried a package wrapped in newspaper. "Dry ice coming up!"

Randy undid the package. There was layer after layer of newspaper to be removed. "Boy, did Mr. Carlson make sure you wouldn't freeze your fingers off!" Randy exclaimed.

Sam frowned. "It's not funny. He told me that if you touch dry ice to your bare skin, it's just like burning it with a red-hot iron."

"We'll be careful," Randy said hastily, looking at his mother. He got the last of the newspaper off and placed the dry ice in the shallow pan full of cotton. Trails of vapor streamed from the ice. Randy quickly covered it up so that it wouldn't evaporate too quickly.

"Now," he announced, "I pour some of this wood alcohol into the cloud chamber."

He added the alcohol carefully, making sure that he didn't inhale the fumes. The bottom strip of cloth in the jar

soaked up most of the liquid, leaving only a fraction of an inch in the bottom.

"Now we tip the jar and soak the top strip, too. Next we close the jar tightly, turn it upside down, and set it on top of the piece of dry ice."

There was a squealing sound.

"Metal molecules in the jar lid protesting! Dry ice *only* has a temperature of 112 degrees below zero!"

Randy arranged the flashlight so that it would shine through the side of the cloud chamber. "And now, Assistant Technician Morrow, douse the lights."

Sam turned off the basement lights. The only illumination now came from the flashlight shining into the cloud chamber. The three Morrows leaned over the little jar and stared.

Nothing happened.

They watched for a long minute. Then—

"Look!" Sam squeaked.

A thin streak of white had appeared in the chamber. They all saw it clearly standing against the black background of the cloth in the jar lid. It hung suspended for an instant, then disintegrated.

"Well, for goodness sake," Mrs. Morrow marveled. "What was that?"

"A cosmic ray," Randy said solemnly. "From outer space."

His mother said, "Cosmic rays?"

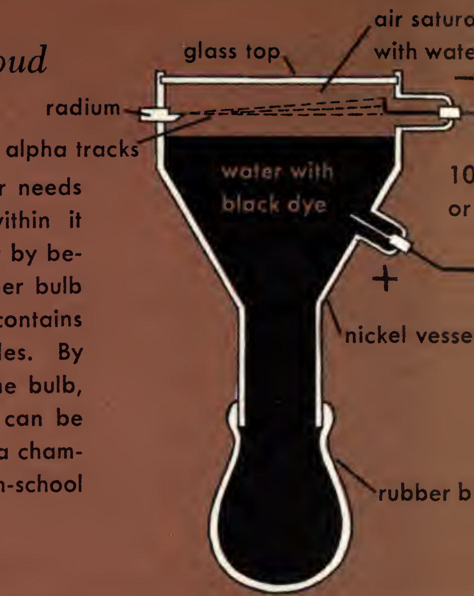
"It could have been a meson—or maybe a proton or some other kind of particle. Mr. Wood says cosmic rays are always hitting the earth. This cloud chamber just makes it possible for us to see them."

"How does it work?"

Randy explained. "The jar is full of alcohol vapor that the soaked pieces of cloth give off. The dry ice cools the vapor

Another type of cloud chamber

This type of cloud chamber needs no dry ice. The vapor within it reaches condensation point by being compressed when rubber bulb is squeezed. This chamber contains a source of alpha particles. By squeezing and releasing the bulb, the tracks of the particles can be made visible. You may see a chamber of this type in your high-school science class.



down to its condensation temperature. When the cosmic ray particle zooms down, it makes ions in its path. Little drops of alcohol condense on the ions and make that cloud track we saw."

"There goes another one!" said Sam. "H'ray!"

They watched the particles for awhile. Then the boys' mother went upstairs, leaving Sam and Randy with the cloud chamber.

Randy snapped the lights on. "I'm going to try something." He got out the dish containing the radioactive paint dust he'd scraped from the clock face. Using a piece of paper, Randy removed some of the dust and held it close to the side of the jar. A few faint tracks appeared.

"Beta particles," Randy said, "or maybe gamma rays. They can go through the glass. Alpha particles can't."

"Let's put the paint dust inside the cloud chamber," Sam

suggested. "Then maybe we'll be able to see the alpha particle tracks."

Randy disassembled the cloud chamber and added more alcohol to the soaked strips. He told Sam to stick a straight pin into a cork, and dip the pinhead into a drop of glue. The sticky substance was touched to the radium paint dust.

Then Randy placed the cork in the center of the cloth disk inside the jar lid, inverted the jar over it, and screwed it tight. He replaced the cloud chamber on its cake of dry ice.

"Kill the lights, Sam."

In the lighted jar, the boys beheld a wonderful sight. Thick cloud streaks radiated in all directions from the head of the pin, as invisible alpha particles came speeding out of the radioactive paint.

"Will you look at that," breathed Sam.

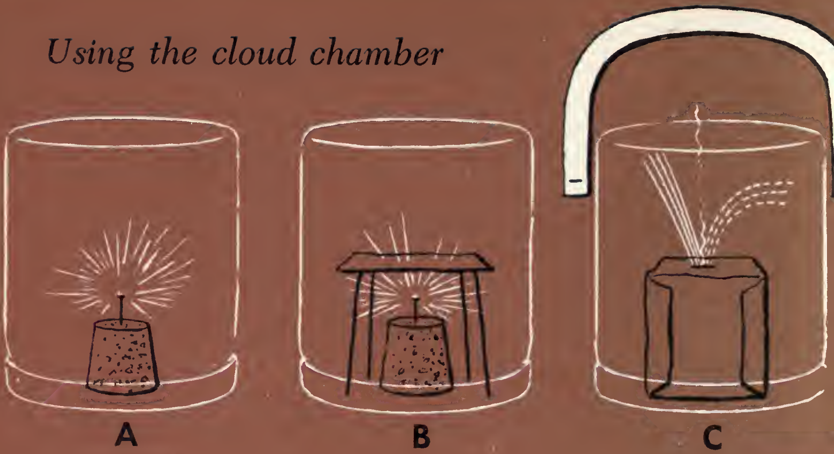
Randy watched the shooting particle tracks for a long minute. "You know, Sam, everybody knows that radium is radioactive. But somehow it never made much of a real impression on me until just now. Look at those tracks! Each one comes from a single particle. And we're seeing them!"

"I wonder what happens to the alpha particles when they stop moving? Those streaks aren't very long."

Randy shrugged. "Each particle is a helium nucleus. When the alpha particle loses its energy it probably swipes a couple of electrons from some nearby atoms and settles down as a neutral atom of helium."

The boys spent the rest of the afternoon experimenting with the cloud chamber. Randy made little roofs out of bent wire and various materials—paper, cellophane, aluminum foil, and toothpaste tube metal. The alpha particles were easily stopped; but other kinds of fainter tracks appeared on the opposite side of the barriers, showing that some kind of radiation had gotten through.

Using the cloud chamber



Radium paint on the head of the pin gives off several kinds of radiation in A. Make roofs of materials like paper, aluminum, and lead foil, shown in B, to screen off alpha and beta radiation. Gammas penetrate several inches of lead. C shows what would happen if you could place a powerful magnet over the cloud chamber. Alpha particles curve toward negative pole, beta particles toward positive pole. Gamma rays follow a nearly straight path.

They used a magnet to attempt to separate the charged particles from the gamma radiation, but the results were disappointing.

"The particles just go every which way," Sam complained, carefully removing the cork-and-pinhead assembly from the cloud chamber.

"We ought to make a little box out of lead foil," Randy decided. "With a narrow slit in it so that only the particles going in one direction can escape. That way, we'd get a narrow stream of particles instead of a wide spray."

"That might work."

They made the little box and tested. It seemed to give

somewhat better results. "We need a stronger magnet," Randy remarked. "Like an alnico magnet. Then we'd really be able to sort these particles out."

"Cloud chambers are sure great," Sam said. "The electroscope let us know that *some* kind of radiation was around—but the cloud chamber shows just what kind of radiation it is!"

"Cloud chambers are fine for some things," Randy said. "But can you imagine a uranium prospector having to lug one of these things along?"

"There's a thought," Sam giggled.

Randy rummaged around in the mess on the workbench and came up with the geiger counter specifications Mr. Wood had given them. "Sam, d'you have any money?"

"What I got for my birthday. Why? You going to build that geiger counter?"

"I'd sure like to. The most expensive thing here seems to be the geiger tube itself. It costs about $3.50. The rest of the parts aren't too expensive. Let's see—headphones. Haven't we got a pair in the junk box?"

"Let's look," Sam said, and dived in.

He came up with the headphones. "A little beat-up," he apologized, "but they'll still work."

"We could build the counter and go prospecting in Beckmann's quarry. Maybe there's ore there!"

"That's nothing but an old gravel pit," Sam scoffed. "They don't even take rocks out of it anymore."

"Nobody ever looked for uranium there," Randy persisted. "There could be the biggest deposit of uranium in the country in that gravel pit—and nobody'd know it. Because nobody ever looked!"

"You really think there might be?" Sam asked cautiously.

"Let's build the counter and find out. I'll contribute

what's in my bank. You want to help grubstake me?"

"Fifty-fifty if we find anything?" Sam hesitated.

"It's a deal. Let's go count up the grubstake."

"Wait!" Sam stood stock still. "I forgot something!"

"What, for Pete's sake?"

"*My* experiment."

"Your experiment?"

"In the closet. My piece of film with the stuff on it. Let's see what happened!"

Sam raced upstairs and got the sealed shoe box. "You can go count your old money," he declared. "I'm going to develop this piece of film and see what the radiation did to it!" He disappeared into the basement where he kept his developing materials. Randy shrugged and went after the banks.

By the time Randy had finished what he called his "money hunt," searching out every bit of change that might have been left in jacket pockets, under seat cushions, in desk drawers, or elsewhere, Sam had finished developing the film.

"Look what happened," Sam announced, holding up the negative.

It was blackened, except in places that had been shielded by the coin and the key chain.

"Radiation exposes film, just like the sunlight!" Sam exclaimed.

"That's pretty sharp, all right," Randy conceded. "Okay, Apprentice Technician Morrow. I hereby promote you to *Junior* Technician."

"Nothing doing," Sam said. "Not if you use my money to build your geiger counter. I want to be the same as you."

"You haven't had enough math," Randy said loftily. "In fact, you haven't had any real math at all. Just arithmetic."

The result of Sam's experiment

When the film negative was developed, Sam found this result. Radiation from the radium paint had exposed the film except in the place where the key chain and penny shielded it. Turn to Chapter 2 to see the results of Sam's experiment.

"I can do fractions," Sam submitted hopefully.

"Well—maybe you can be a Senior Technician, Second Class."

"What does that mean?"

"That means you get to hold the geiger counter half of the time."

"Okay," Sam said.

"Not all the time?"

"No, sir, just half the time."

"And now we've got to get over to the electronics store before it closes!"

CHAPTER 7

The uranium prospectors

THE electronics store was a big place, taking up nearly a whole city block.

"They ought to have all the stuff we need," Randy said. "Come on."

The boys wandered inside. Equipment covered every shelf and counter. Color television sets, ham radio transmitters, oscilloscopes, ship's radar sets, intercoms—all the latest electronic devices seemed to be crowded into the store. A salesman approached them.

"Looking for something special, boys?"

"I have a list of parts here," said Randy.

"Parts department is on the far wall, to your left."

Randy and Sam found the right place and handed their list over to another salesman.

"Building a geiger counter, eh, boys?" the man remarked.

"That's right," Randy said.

"We're going prospecting!" Sam piped up. Randy poked him in the ribs.

The salesman laughed. "That right? Well, well." He began to read down the list of parts, checking them against the stock in his catalog.

Geiger counter tube—Raytheon CK 1026
Spring clip for tube
Resistor, 47,000 ohms
Neon lamp, NE-2
Condenser, .0005 mfd, 150 v. (or higher)
Condenser, .005 mfd, 600 v., 1000 v., or 1600 v.
Transformer, Thordarson 20A00
Phone jack
Toggle switch
Buzzer, Edwards 1872 or similar
3—Size D flashlight cells
Four-terminal strip

"No headphones?" the salesman wanted to know.

"We've got some at home," Randy said. "From a crystal set we made once."

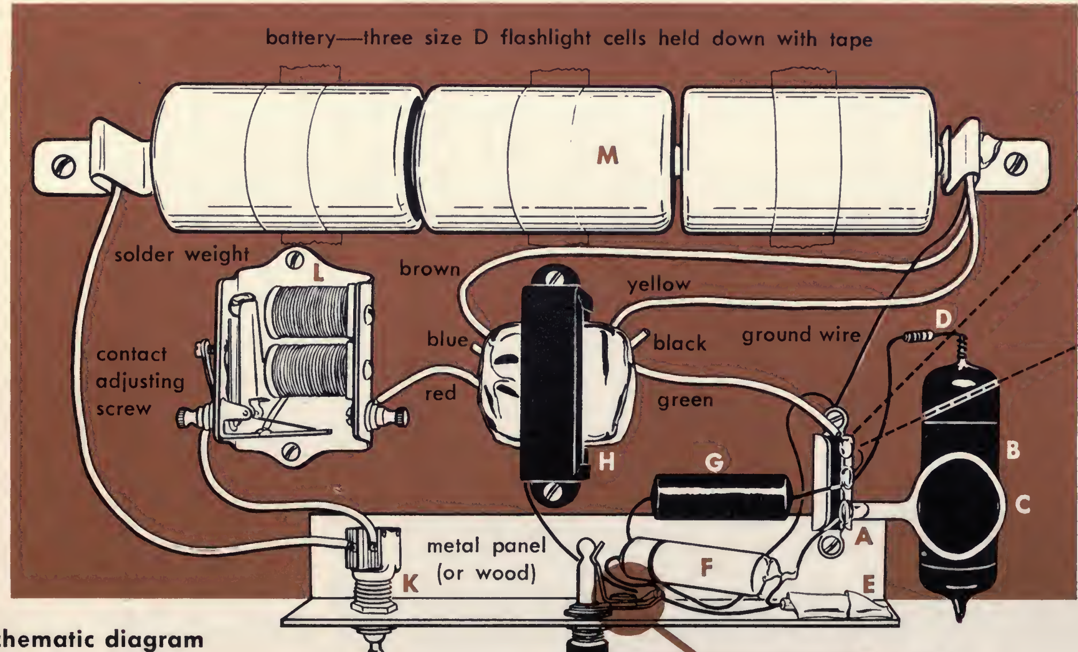
"I'll be a couple of minutes getting these," the man said, and disappeared into the stockroom.

Randy and Sam spent the time looking over professional radiation detectors. This collection made the number of instruments they'd seen at the sporting goods store look skimpy indeed. Here were not only portable devices designed for prospecting, but large laboratory-type detectors that must have weighed several hundred pounds.

"Look at this," Randy said. "Here's a geiger counter do-it-yourself kit. It's a lot more expensive than our home-made job will be, though."

"We could really do a job of prospecting with one of

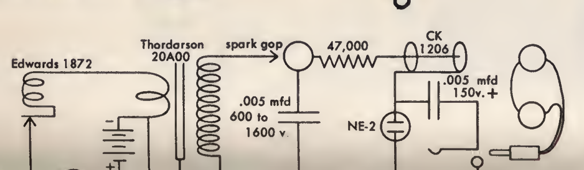
Here's how to build Randy's Geiger counter



Note: If counter fails to work—

1. Add one or more additional batteries to circuit.
2. Adjust contact screw of buzzer.
3. Adjust spark gap with pencil.

Schematic diagram



How the Geiger counter works

The buzzer interrupts the battery current flowing through the transformer primary winding. The resulting rapid change in magnetic field in the transformer core induces a high-voltage pulse, about 2,000 volts, in the secondary winding.

The spark gap acts as a one-way valve or rectifier, permitting current to flow from the transformer during the high-voltage pulse to charge the .005 mfd condenser to a voltage of about 900 volts. This voltage is not high enough to break down the air in the spark gap, so current does not flow the other way between pulses.

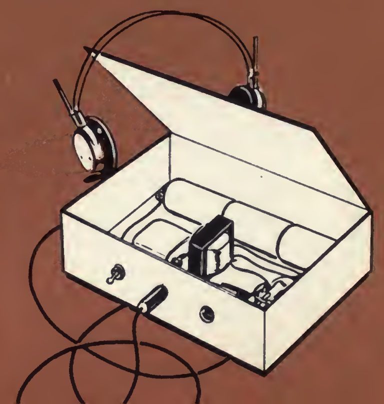
If the spark gap is too short, bright sparks will occur when such a reverse current flows, and condenser voltage will not be high enough to operate counter. If spark gap is too wide, the high-voltage pulses will not cause sparks to charge the condenser to a high enough voltage to operate the counter.

In the buzzer, the contact spacing is increased and the spring tension reduced so that the buzzer operates on less than the rated voltage. If the buzzer is not adjusted in this manner, you will need more flashlight cells to operate the counter. The buzzer is not intended to make noise, but simply to interrupt the transformer primary current. For this reason, the buzzer armature is weighted with a lump of solder to make it operate at a lower frequency. The resulting low-pitched sound is less audible and distracting.

WATCH YOUR SPARK GAP. It is operating correctly if intermittent blue flashes occur. Bright flashes indicate that the gap is too short. Absence of flashes indicates gap is too wide. Adjust gap with wooden pencil or you will get a shock.

List of parts

A 3-terminal strip
B Geiger Tube Raytheon CK-1026
C Spring clip for tube
D Resistor—47,000 ohms
E Neon Lamp—NE-2
F Condenser—.0005 Mfd, 150 v. or higher
G Condenser—.005 Mfd, 600v, 1000v, or 1600v
H Transformer—Thordarson 20A00
J Headphone jack
K Toggle Switch
L Buzzer, Edwards 1872 or similar
M 3 Flashlight cells—'D'



these," Sam said wistfully, eyeing a $750 scintillation counter.

"Our gizmo will do the job," Randy said. "And for Pete's sake, stop popping off about us going prospecting. Do you want somebody else to beat us to the claim?"

"Aw, who'd do that?"

"You never can tell. Just keep this under your hat."

The salesman finally returned with a small cardboard box full of components. He added up the bill, and the boys produced their money.

"Good luck on your prospecting, fellas," he said. Randy winced, but thanked the man courteously. Then the boys fled.

The geiger counter construction proved easier than Randy had thought. He simply laid out the circuit diagram that Mr. Wood had given them, arranged the components on a board in the same manner, and fastened them down. The wiring was done with the aid of their father's soldering iron. The geiger tube itself was mounted near one end of the board.

Sam was assigned to construct a housing for the geiger counter out of an old cigar box.

"We can put some hinges and a catch on this housing," Sam said. "I'll make a handle for the top, too."

When the soldering was completed, Randy said, "Get one of our radiation samples and we'll try her out."

Sam set up one of the corks with a pinhead source of radium stuck in it.

Randy plugged his headphones into the phone jack of the geiger counter and threw the toggle switch. "I get background radiation," he said. The little neon lamp began to blink fitfully.

"We're off!" Randy exclaimed. He advanced on the radi-

Gamma rays important to uranium prospectors

Penetrating gamma rays come through a foot or more of ground. Alpha and beta radiations are much weaker. The detection instrument of the prospector is sensitive to gamma radiation.

ating pinhead, and was rewarded by an increase in the number of sputtering clicks in his earphones.

"Gamma radiation," Randy said. "That's what's coming across. Those are the most important radiations to prospectors."

"Why?" Sam wanted to know.

"Because they can penetrate rock. Say you're standing over a deposit of uranium that's buried under a couple of feet of dirt and rock. The gamma rays might still be able to get out and give an indication on your geiger. But the betas and alphas will all be absorbed by the dirt and stuff. You'd have to find a piece of ore outcropping on the surface before you'd detect its beta radiation."

"Let me try the thing," Sam demanded. Randy handed it over.

"Too bad we can't calibrate our geiger," Randy said. "Oh, well. We can just estimate the number of background counts per second. That'll give us something to go on."

When Sam was finished with his testing, the boys attached the housing to the board. The completed instrument was wrapped in brown paper.

"We're all set for tomorrow," Randy said. "Lucky thing it's Saturday. Be sure to get a notebook and pencil."

"Will do," Sam said. "Forward, noble geigermen!"

They stood on the rim of the gravel pit, looking into its depths.

"This thing must be 100 feet deep," Sam said in awe. "Look at that pool of water!"

The great expanse of Beckmann's quarry was silent and desolate. A few hardy shrubs sprang out of the crevices in the rock walls, but outside of this meager greenery, there wasn't a living thing around.

"Gives you the creeps, doesn't it?" Randy said. He finished unwrapping the geiger counter. "Come on, let's head down this way."

The boys found an inclined roadway that must have served the excavating equipment many years ago. By now, the road was half eroded away. Rock falls obstructed parts of it, and the boys had to pick their way downward with great care.

"For Pete's sake don't break your leg," Randy warned Sam. I'd never be able to lug you *and* the geiger counter out of here."

They slid down a rock pile and came to a halt.

"Let's try here," Sam puffed.

Randy agreed. He drew out the notebook and sketched a rough map of the quarry.

They moved farther down. The color of the rock changed.

"Here's where we are now," he said, marking an X. "We'll call this Location A. From now on, you keep the log. Mark each location we test, and keep a separate list showing whether we get any reading."

Randy switched on the counter and began nosing around the rocks.

"Anything?" Sam called.

"Can't tell." Randy circled around, then worked his way back. He removed the phones and turned off the counter.

"It seems a little bit hotter around here," Randy said. "But I could be mistaken. Let's go down a little farther and try again."

"What shall I put in the notebook?" Sam asked.

"Mark it, 'inconclusive.' "

"I-N-C—" Sam spelled out. "Aw, nuts. I'll just put a question mark."

They worked their way farther down. The color of the rock began to change slightly.

Suddenly Sam yelled, "Yoy!" The echoes of his voice went bouncing across the great pit.

Yoy! Yoy! Yoy!

Randy whirled around. "Did you hurt yourself?"

Sam grinned. "Nope. Just testing the echoes."

"You dope," Randy said. "You'll have half the county here. Pipe down."

They reached a small plateau that Randy designated Location B.

"This time I want to do it," Sam demanded.

"You want to *monitor* it," Randy corrected. "You monitor with a geiger counter. Okay, go ahead. Hold it close to the ground."

Sam prowled around busily. "Seems like a lot of clicks," he reported.

"Let me try," his brother ordered. He took over the instrument and retraced Sam's steps. "It is a little hotter, all right."

"Feels kind of chilly to me," Sam said. "Wish I'd brought my heavy jacket."

"Hot as in radioactive-hot," Randy said. "There seem to be more clicks down here. Mark it 'increased activity.' "

They had nearly approached the level of the water that covered most of the bottom of the quarry. A third place, Location C, gave definite indications of being slightly radioactive.

They worked around an ancient rusted power shovel that had been abandoned there years ago, and monitored several more spots. Finally, Randy sat down and studied the note-

He began to bury the can with the claim in it in the rock cairn.

book intently, and at considerable length.

"I'll bet we did find an ore body," he said softly. "Look. Over on this side of the pool the count is pretty much background radiation. But over here, the rocks are definitely hot!"

"We gonna stake our claim?" Sam asked.

Randy nodded. "And we'll have to take a hunk or two to be assayed. That's how they always do it. You take it to the assay office and find out how much of a percentage of radioactive metal is in your ore."

"Where do we find an assay office?"

Randy was stumped. At last he said, "Maybe we could get my chemistry teacher, Mr. Albert, to run some tests."

They decided to take a few samples of the hotter rocks. "Should have brought a hammer," Sam grunted, trying to smash off a smaller piece of a particularly good specimen.

Randy was busy staking the claim. He heaped up four stacks of rock at the corners of what he thought was the most radioactive area. He found a rusty old tin can near the defunct power shovel, and inserted a sheet of paper into it.

"What's that say?" Sam inquired.

"It's just our claim," Randy said. "I put down our names and the date, and wrote 'Claim-jumpers will be prosecuted to the full extent of the law.' "

"That oughta fix 'em," Sam said grimly. "But don't you have to register your claim first?"

"I'm not sure," Randy mused. "I'll have to look it up when we get home. Anyway, it won't be a bad idea to stake this out."

He began to bury the can with the claim in it in the largest rock cairn. Sam wandered off and began to toss rocks into the black waters of the pool. The sound reflected eerily off the walls of the pit. The sky had grown ominously cloudy.

"All finished," Randy announced. "Let's get out of here."

"I'm with you," Sam agreed. "This place is beginning to give me the willies."

They repacked the geiger counter in its brown paper, stuffed their pockets with sample rocks, and began the long climb back up the quarry walls.

On Monday, Randy approached his chemistry teacher after class. He produced one of the best rock samples they'd picked up.

"Can you help us assay this, Mr. Albert?" he asked. "It might have uranium in it."

Questions for uranium prospectors

1 Is this material uranium ore?

2 Is the quality good enough?

3 Is there enough ore to be worth mining?

The instructor turned the rock over and examined it. "So you found yourself some radioactive ore, eh, Randy?"

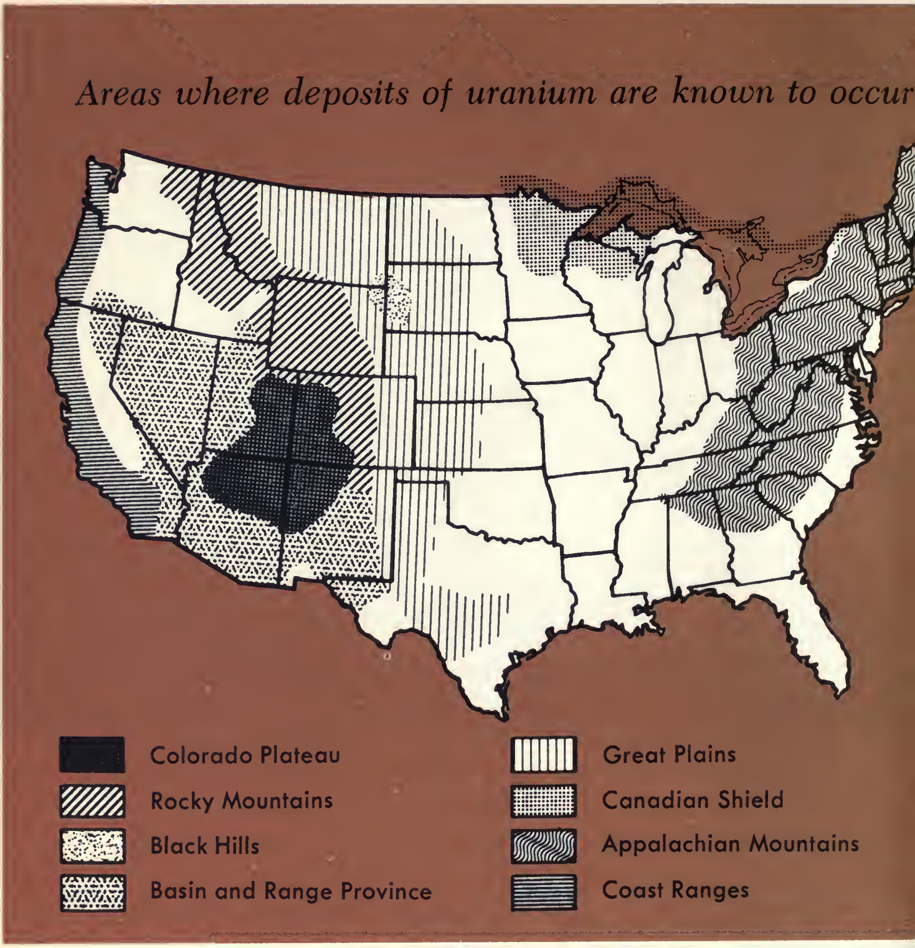
"It looks that way, Mr. Albert. Of course, it wasn't *very* radioactive, but I thought—"

"You thought it might be valuable. Well, I'll run a few tests on it. Come back later—after classes this afternoon."

The day crawled by for Randy, but finally it was 3:30. He streaked over to the chem lab. The teacher had pulverized a small portion of the rock and was testing it with several different chemical reagents.

"How does it look?" asked Randy anxiously.

"Just a minute more." Finally, Mr. Albert said, "Randy, this piece of rock you brought is a fine piece of native limestone."



"Limestone!" Randy groaned.

"Limestone. It has a trace of radioactivity, just as many common rocks do. But it would have no commercial value as an ore. There's far too little of the radioactive material in it."

Randy's head dropped. "I guess I made a boob out of myself, didn't I."

"Not at all," the chemistry teacher said. "You've built yourself a geiger counter, and you've had a lot of fun

prospecting with it. Unfortunately, the rocks in this area aren't the type that generally contain radioactive deposits. You want to go up to the Algoma region in Ontario above the Great Lakes, or out to the Colorado Plateau area in the west. Radioactive ores *are* found there. Several men have made fortunes by locating rich deposits."

Randy's spirits began to revive. "My Aunt Jane lives in Boulder, Colorado. Sometimes we visit her during summer vacation."

"It's rugged country out there, but prospecting is a fascinating business."

"You don't think I wasted my time then?"

"Randy, I'm pleased that you're interested in scientific things. There's no hobby like science for helping young people decide their future careers."

"Well, I don't think I'd fit into the life of an atomic age sourdough," Randy laughed, "but I was thinking seriously about entering the field of atomic energy."

"Good for you. Have you done any other experiments besides the geiger counter?"

"Dad helped me make an electroscope, and a friend of his at Argonne showed me how to make a cloud chamber and the counter."

"Would you like to make a spinthariscope?"

"Sure! Uh . . . what's a spinthariscope?"

"A device that makes radioactive disintegrations visible as small flashes of light."

Mr. Albert went to a cabinet full of chemicals and got out a bottle. "Here's some zinc sulfide. I'll put some in an envelope for you. This chemical glows when struck by alpha particles. I'll tell you how to make the spinthariscope, if you'll promise me something."

"What, Mr. Albert?"

"That you'll bring the instrument to class so that everybody can have a look at it."

"It's a deal!" Randy said.

CHAPTER 8

Bullets for the nucleus

RANDY was in the midst of constructing the spinthariscope when his father strolled down into the basement.

"I hear you guys have really taken the atomic energy business to heart," he said.

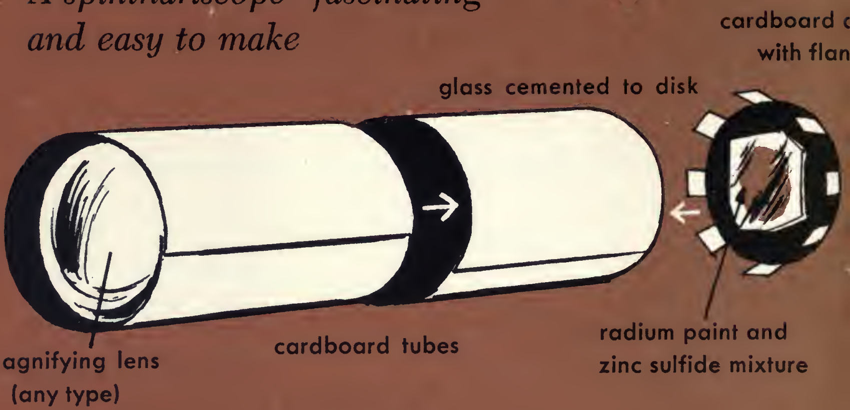
"It's really interesting, Dad. I got a bunch of books from the library. Samuel Glasstone's *Sourcebook on Atomic Energy* and Selig Hecht's *Explaining the Atom* are two Mr. Wood recommended."

"Fine! I just might be able to arrange a visit to Argonne for you, if you're really keen on this."

Randy put down the pieces of the spinthariscope. "*Would* you, Dad? Boy! That'd be something!"

"I'll talk to Mr. Wood about it. And I know a man in the

A spinthariscope—fascinating and easy to make



The tube with the lens fits tightly inside the tube with the disk. Both are painted on the inside with black poster paint. A little rubber cement on flanges fastens disk to end of tube. To see scintillations, move tubes in and out to focus, be sure no light enters spinthariscope.

public relations department who can probably swing it."

Mr. Morrow looked over the latest project of the Morrow Atomic Laboratory. "What's this you're building?"

"A spinthariscope. It's really simple. I got this magnifying glass at the dime store and took the lens out of the frame. Then I rolled a 3-inch cardboard tube to the diameter of the lens, and mounted the lens about an inch down in the tube. It's fastened with cement."

Mr. Morrow picked up a second tube with a slightly larger diameter than the one with the lens. "What's this?"

"That tube fits over the first one, like a telescope. I'm going to mount this disk in the end of the second tube."

Randy showed the disk to his father. It had been painted dull black with poster paint, and was of the same diameter

as the large tube. Several small flanges on the outer rim would be used to fasten it into the tube. A flat piece of glass was glued in the center of the disk. In the middle of the glass was a smear of yellowish stuff.

"What's this on the glass?" Mr. Morrow asked.

"A mixture of zinc sulfide and radium paint dust: I pulverized them and mixed them together. Then I brushed a little glue on the glass and sifted the powder into it. As soon as I finish painting the insides of these tubes black, the spinthariscope will be ready to work."

"Be sure to wash your hands after working with that paint," Mr. Morrow cautioned.

"I'm handling it with care," Randy said.

Randy explained that the alpha particles emitted by the radium would strike the molecules of zinc sulfide and cause a flash. The magnifying lens would make it possible to see each tiny flash.

"Here we are, all dried," Randy announced. He touched glue to the flanges on the disk and mounted it in the end of the large-diameter cardboard tube. Then he assembled the two tubes and peered inside.

It took a minute or two for his eye to become accustomed to the blackness. He moved the lens tube in and out slowly, keeping his hand over the junction of the tubes to keep the light out.

"I see them!" he cried suddenly.

The spot of paint and zinc sulfide was lit by hundreds of tiny flashing points of light. Each spark was caused by a single alpha particle.

"Want to look, Dad? Just move the tubes in and out to focus it."

Mr. Morrow took his turn at the spinthariscope. While he was looking, Sam showed up.

"What's cooking?"

"A spinthariscope," said Randy. "You can look when Dad's finished. You never saw anything like this, boy!"

Sam finally adjusted the little device to his eyes. He peered intently for an instant, then said, "*This* is nothing new!"

"What d'you mean?" Randy bristled.

"I'll show you," his brother said, and dashed upstairs. He returned in a few moments with something clutched in his hand. "If you send in a quarter and a box top to the TV Rocket Rangers," he said, "they'll send you one of these atomic rings."

He dropped the trinket into Randy's palm. The thing was an adjustable metal ring with a little bomb-shaped metal capsule mounted on top. The fin end of the bomb was really a removable plastic cap.

"Take off the cap and peek inside the bomb," Sam invited.

Randy did so. "For Pete's sake!" he exclaimed. "A little bitty spinthariscope!"

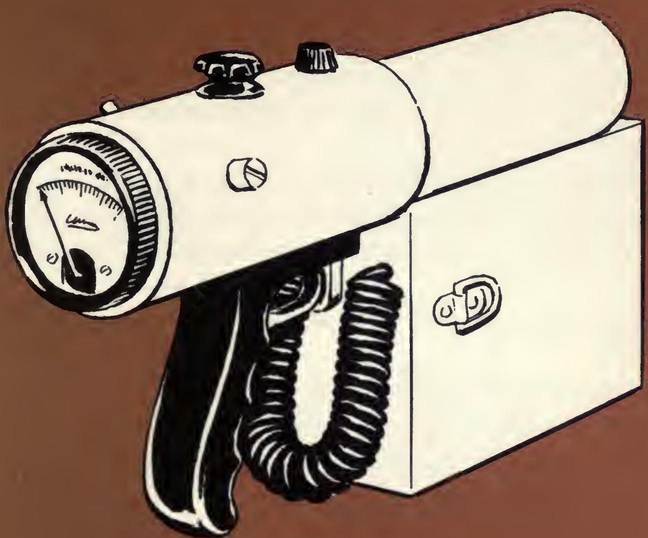
Mr. Morrow laughed. "Spinthariscopes for box tops! We're certainly living in the atomic age!"

"But this thing is just a toy," Randy said disgustedly. "The spinthariscope can be modified into a really useful instrument. Mr. Albert told me."

"You're right, Randy," the boy's father said. "The scintillation counters we saw are based upon the spinthariscope. Scintillation is just a big word for a little flash of light. The instrument counts the flashes on its screen with an electronic gadget called a photomultiplier tube. Scintillation counters for alpha particles use zinc sulfide screens. Counters for other particles use other chemicals on their screens."

"Are scintillation counters better than geiger counters?"

Scintillation counters also measure radiation



When particles of radiation enter the scintillation counter, they strike a crystal and produce tiny flashes of light. A photoelectric cell and meter circuit record the number of flashes. This device is much more sensitive than the geiger counter.

Sam asked, utterly fascinated with the information.

"They can work more rapidly," Mr. Morrow said. "And they're more accurate in measuring radiation of high intensity."

"Which kind of radiation has the highest intensity?" Randy wanted to know.

"Radiation can have different intensities. What I really mean to say is, it can have different energies. Devices like the geiger tube and scintillation counter count the *number* of particles that strike them. But they can't directly measure

the energy behind the particles. This has to be done indirectly by measuring how far the particles travel through air or through another medium."

Randy said, "I know that energy is usually measured in erg units, Dad. Are ergs used to express the energy of radiation?"

Mr. Morrow shook his head. "The erg is too big. The basic unit in atomic studies is the *electron-volt*. It's abbreviated to e.v. A million electron volts is an M.e.v., and a billion is a B.e.v."

"Ev, mev, bev," said Sam. "And *I* don't even know what an erg is!"

"How about it, Randy?" Mr. Morrow asked.

Randy screwed his forehead up. "Short pause while I rack my weary brain. Got it! It's the work done when a force of one dyne moves an object weighing one gram a distance of one centimeter!"

"Big deal," said Sam. "Now what's an electron-volt?"

"A million electron-volts equal about 16 ten-millionths of an erg," Mr. Morrow said.

Sam's eyes popped. "They can measure something that small?"

"They can calculate it," Mr. Morrow said.

"I don't see what good it would do," Sam muttered.

"Have you ever heard of a cyclotron?" Mr. Morrow asked.

"Sure! Everybody knows about cyclotrons! They're atom smashers."

"How do you smash an atom?" Mr. Morrow asked.

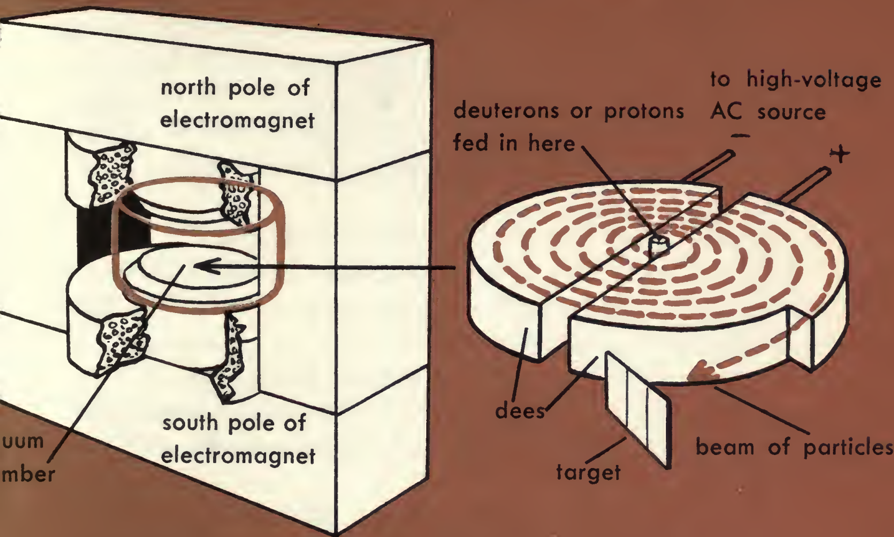
Sam sat there. "I don't know," he said lamely.

"I'll bet it has something to do with electron-volts," said Randy.

"You're right," his father agreed. "Shall we figure it out?"

Mr. Morrow explained that an atom could be changed by

A cyclotron produces atomic bullets



The cyclotron speeds up particles until they acquire great energy. The hollow boxes called "dees" are electrodes connected to a high-voltage alternating current source. The action of the current in the field of the electromagnet causes the particles to whirl round and round in a spiral path. By the time they reach the outside of the box, the particles are moving with great speed. They strike the target and cause nuclear changes in target atoms.

bombarding its nucleus with particles that had been speeded up until they possessed a high electron-voltage.

"There are many types of particle accelerators," he said. "The cyclotron is only one type. Other kinds have names like synchrotron and Cockcroft-Walton and Van de Graaf accelerators. All of these devices take particles and speed them up until they attain energies of several million or even

several billion electron-volts."

"How does the cyclotron work?" Randy asked.

"You can see how by tying a ball to the end of a long string and whirling it around your head. As the ball goes faster and faster, it acquires more energy. The cyclotron whirls particles the same way—then it hurls them at a target of some element. The high-energy particle strikes a nucleus—"

"Bingo!" said Randy. "The nucleus falls apart!"

"Not always," Mr. Morrow laughed. "Atomic bullets are absorbed by the nucleus. Then the nucleus reacts. The bullet disturbs its internal balance."

"The nucleus becomes radioactive," Randy put in.

"That's the right way to put it. The nucleus might eject a particle to stabilize itself, or it might actually split into fragments."

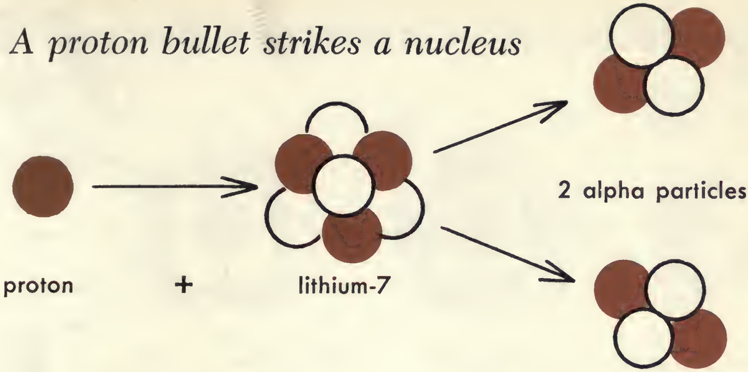
Sam said, "I still don't get why atomic bullets have to be speeded up. Why not just take some radioactive element—say radium—and put your target where the alpha particles will hit it?"

"As a matter of fact, Sam, that's exactly what *was* done during the early days of atomic experimenting. You can read how Sir Ernest Rutherford performed this experiment early in the 20th century. The first controlled nuclear disintegration was done in just this way, before the uranium atom was split in 1938.

"Well, why not do it this way now?"

"The alpha particles from radium just don't have enough energy to affect more than a few atomic nuclei. Heavy nuclei with many protons and neutrons repel alpha particles. Scientists had to find new kinds of bullets with enough energy to penetrate to the nucleus. You wouldn't use a .22 bullet on a rhinoceros, even though it might be all right for

A proton bullet strikes a nucleus



formula: $_3Li^7 + {}_1H^1 \longrightarrow {}_2He^4 + {}_2He^4$

a squirrel."

"Then these accelerated particles act like magnum bullets?" asked Randy.

"More or less. They have enough energy to reach the nucleus. They're not repelled by the strong positive charge that surrounds it. The bullets are absorbed. What happens next depends upon the type of nucleus and the type of particle that penetrated it."

"Can we figure out what happens when different kinds of particles are used as bullets?" Randy asked.

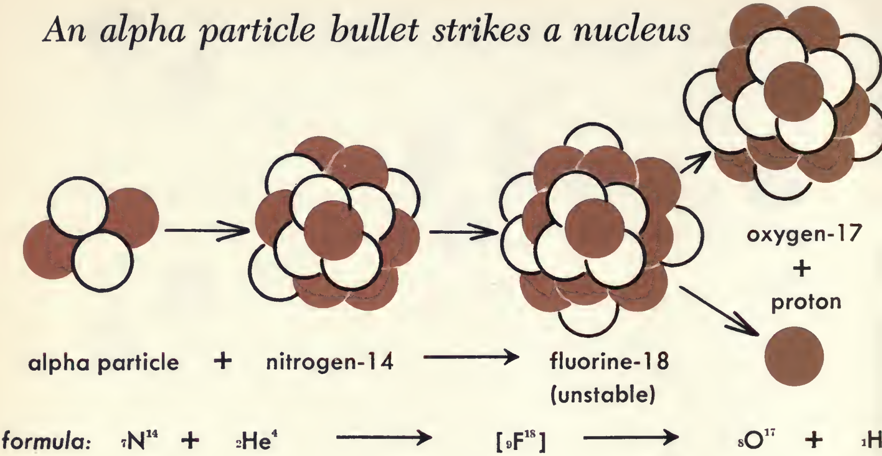
His father said they could.

They learned that—besides alpha particles—protons, neutrons, deuterons, and electrons were used as atomic bullets. "Tritons are used, too," said Mr. Morrow, "but since they're relatively new, I'm not too sure how the reactions go. Some new accelerators will be able to speed up heavier nuclei—like oxygen and neon."

"Let's try the easier reactions," Randy suggested.

"Well, one early experiment involved shooting protons at lithium metal."

An alpha particle bullet strikes a nucleus



Mr. Morrow took a piece of paper and wrote:

$$_3Li^7 + {_1H^1} \rightarrow {_2He^4} + {_2He^4}$$

"Wow!" exclaimed Sam. "That looks complicated!"

"It's really very simple. One atom of lithium-7, plus a proton, gives two atoms of helium-4. The upper numbers are the atomic weight—the sum of the protons and neutrons in the nucleus. The lower numbers are the positive charges on each nucleus."

"I get it," Sam said.

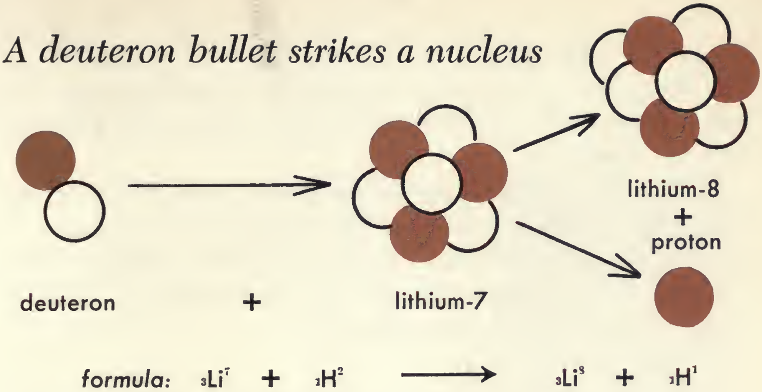
Mr. Morrow said, "Notice that the total number of positive charges and the total atomic weight are the same on each side of the equation. The total number of charges is 4 and the total weight is 8."

"That's pretty easy to understand," Randy said. "Let's try another one."

"All right. Let's see what happens when we shoot an alpha particle at nitrogen."

$$_7N^{14} + {_2He^4} \rightarrow [_9F^{18}] \rightarrow {_8O^{17}} + {_1H^1}$$

A deuteron bullet strikes a nucleus



"Here the nitrogen absorbs the whole alpha particle. For an instant, it becomes a nucleus of fluorine-18. But this is a very unstable nucleus. One proton is tossed out, and the nucleus settles down as oxygen-17."

"How do you know whether the nucleus will break up or just readjust itself?" Randy asked.

His father shrugged. "A physicist could shed some light on that, Randy, but I honestly don't know. I suspect that much of the time they just fire the bullet and analyze the pieces!"

Sam said, "Dad, show us what happens when a beta particle hits."

"They use a betatron to accelerate beta particles," Mr. Morrow said. "But electrons rarely cause transmutation of elements. Most of the time, they cause high-energy x-rays. These x-rays are themselves used to bombard nuclei."

"Well, how about deuterons?" Randy asked.

Their father obliged with another equation:

$$_3Li^7 + {_1H^2} \rightarrow {_3Li^8} + {_1H^1}$$

"That didn't change much," Sam said. "You started out with lithium and hydrogen, and you ended up with lith-

ium and hydrogen."

"But different isotopes," said Randy. "Don't you see? The deuteron—that's the hydrogen-2—gave one of its neutrons to the lithium-7."

"Yielding lithium-8 and hydrogen-1," said Mr. Morrow.

"I don't see any neutron in the equation," Sam said.

"You just subtract the number of positive charges from the atomic weight, and what's left is the neutrons. Lithium-7 has 4 neutrons. Lithium-8 has 5."

"*I* get it!"

"Good," said Mr. Morrow. "We're going to find out more about neutrons. They're the most important atomic bullets of all. Without the neutron, we could never have harnessed atomic energy!"

C H A P T E R 9

Neutrons and ping-pong balls

"I'M GOING to show you how to make a nuclear chain reaction right here in the basement," Mr. Morrow said.

"Mom isn't going to like that," Sam said ominously.

His father laughed. "I mean a *model* chain reaction. The only material we'll need are mousetraps, ping-pong balls, and a cardboard suit box."

The boys located about ten of the balls among the sports equipment. Most of them were much the worse for wear, but Mr. Morrow said this didn't matter. However, only three mousetraps were available.

"That's not enough. Sam, you're elected to go over to the hardware store on your bike and pick up another dozen mousetraps. Get about two dozen more ping-pong balls, too. We can always use ping-pong balls."

"Gee, why do I always have to go?"

"You want to see the chain reaction, don't you?" asked his father.

"Well, yeah, but—"

"Tell you what," Mr. Morrow said. "You get the materials, you get to set off the chain reaction. Okay?"

"Okay!" Sam disappeared.

Randy asked, "What do neutrons have to do with chain reactions?"

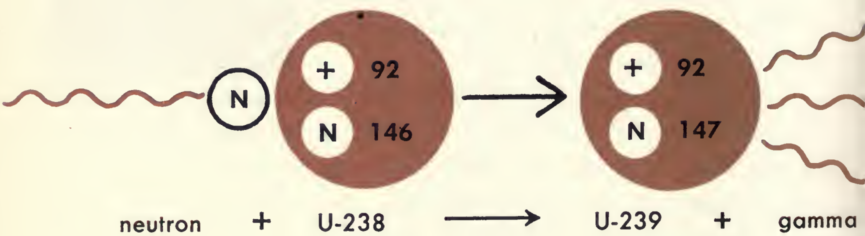
"That's what we're going to find out. Neutrons are tricky little critters. They have no charge, so they can sneak around among the atomic nuclei and penetrate them rather easily."

"Do scientists accelerate neutrons?" Randy asked.

"Not usually. Because it has no charge, a neutron doesn't need a lot of energy to enter a nucleus. Sometimes it seems that the more slowly a neutron moves, the more likely it is to penetrate a nucleus."

Transmutation of an element

How uranium-238 changes into plutonium-239.



The first man-made heavy elements were produced by this means. Bombarding U-238 with a fast neutron sets off a string of nuclear changes that eventually yield plutonium-239.

"That seems funny, Dad."

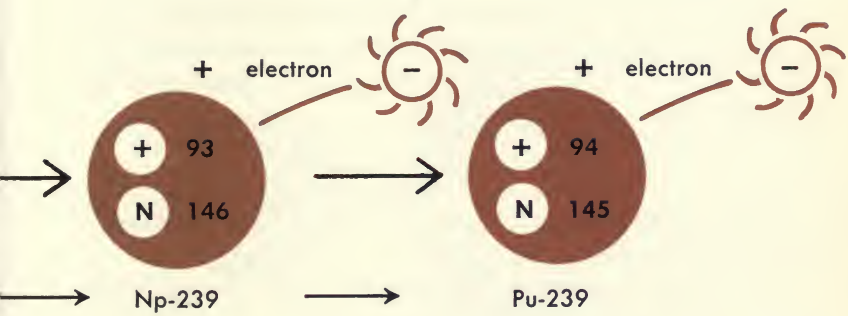
"And there's another thing. Some nuclei tend to absorb slow neutrons, while others show a preference for fast-moving ones. This is very important. In fact, this choosiness is the real key to man-made atomic energy!"

"Let me get this straight. Can you give me an example of choosy nuclei?"

"Certainly. You know that uranium has several isotopes. The important ones are uranium-235, with 92 protons and 143 neutrons; and uranium-238, with 92 protons and 146 neutrons. As it happens, U-235 absorbs *slow* neutrons, while U-238 takes up *fast* neutrons. You'll be able to see how important this is when we talk about atomic reactors."

"Okay," said Randy. "Now, how about showing me what happens when a neutron hits a nucleus?"

His father said, "I'll show you one of the most famous neutrons reactions, the bombardment of U-238 with fast neutrons. The first man-made heavy elements were pro-



duced by this process."

Mr. Morrow wrote the equation:

$$_{92}U^{238} + {_0}n^1 \rightarrow {_{92}}U^{239} + \text{gamma rays}$$

"That might look tough to understand, but it's not. The U-238 takes up a fast neutron and becomes U-239. It gains one unit of atomic weight, but its positive charge remains the same. Now U-239 is a very unstable isotope with a half-life of only 23 minutes. When it breaks down, it throws off a negative beta particle and becomes a new element, neptunium-239."

$$_{92}U^{239} \rightarrow {_{93}}Np^{239} + {_{-1}}e^0$$

"Do you see how it works, Randy? In this reaction the atomic weight stays the same because the beta particle weighs next to nothing. But the positive charge is increased by one unit."

Randy studied the equation for a minute. "I see. One of the neutrons in the U-239 turned into a *proton* by tossing out a negative charge."

"That's right. Now this neptunium is unstable, too. It has a half-life of about two days. Then the nucleus throws out still another negative beta particle, and becomes another new element—plutonium-239."

$$_{93}Np^{239} \rightarrow {_{94}}Pu^{239} + {_{-1}}e^0$$

Randy said, "This reaction is just like the other one. And is plutonium radioactive, too?"

"Yes, but its half-life is about 24,000 years. It gives off an alpha particle and turns into uranium-235!"

"Uranium to neptunium to plutonium—and then back to uranium-235 again!" Randy studied the equations again and scratched his head. "It doesn't seem too hard to under-

stand—as long as you know in advance what's going to happen. But how can you tell whether the nucleus will throw off beta particles or alpha particles or *anything?*"

His father smiled. "I sympathize with your confusion. I wish there was an easy explanation. Scientists have worked out complicated equations to predict the behavior of particles. A nuclear physicist might be able to explain all this stuff so it would seem easy as pie. But your poor old Dad has all he can do to add and subtract atomic weights!"

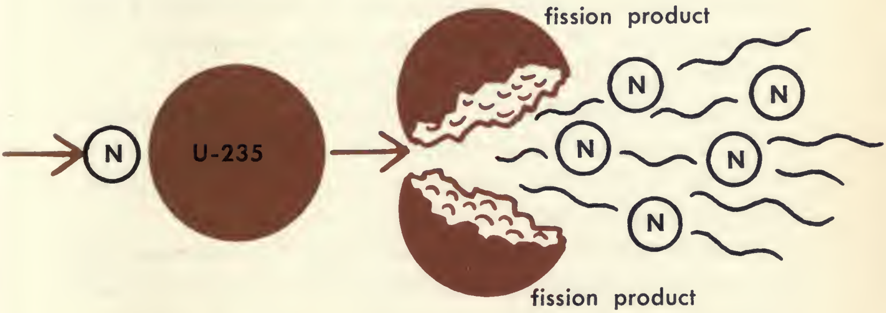
Randy laughed. "Now you're just giving me the business."

"Maybe I am. Well, let's look at genuine atom-smashing now. Nuclear fission. This time we'll work with the isotope U-235, with 92 protons and 143 neutrons. It doesn't want to absorb fast neutrons like its brother, U-238. It prefers slow neutrons."

"All right, Dad. What happens when U-235 gets a slow neutron?"

Fission of an element

How uranium-235 splits, releasing neutrons and energy.



Bombarding U-235 with a slow neutron causes the nucleus to split into two nearly equal pieces. Fast neutrons and a great quantity of energy are released.

"The nucleus takes up the neutron. But it doesn't simply rearrange its particles like U-238 did."

"It doesn't?"

"No. This isotope splits into two smaller nuclei, roughly the same size. The pieces are called fission products. Besides the two smaller nuclei, there are a bunch of neutrons left over, and a tremendous quantity of energy released."

"What are the fission products, Dad?"

"Well, they range in atomic weight from 72 through 158, because the nucleus can break up into many different-sized pairs of fragments. Analyzing the fission fragments is a very complicated job. It's made extra difficult by the fact that many of the products are radioactive, and decay by emission of beta particles into still *other* elements!"

"Wow! How many different isotopes are there among the fission products?"

"Probably about 250."

"What a job to separate them!" Randy said. "But I'll bet it's a fascinating one, too."

His father nodded. "Besides the fission products, the split uranium yields fast neutrons. We'll worry about these when we make our mousetrap chain reaction. The third, and most important, product of nuclear fission is energy."

"Where does the energy come from?"

"It was formerly holding the uranium nucleus together. It gets the name *binding energy* because it binds the separate particles into one compact nucleus. Split the nucleus, and you release some of the binding energy."

"I see. Some of the binding energy would be released, and the rest of it would be used to bind the fission product nuclei together. Right?"

"Right. And the binding energy that's released is the atomic energy that can run power plants or blow up cities.

I'm going to show you just where this energy comes from, and how you can figure it out."

Mr. Morrow explained that the atomic weight of a proton and a neutron was only *approximately* one. By using painstaking methods, scientists had found that the exact weight of a proton was 1.00758. A neutron was slightly heavier, weighing in at 1.00893.

"Remember helium?" Mr. Morrow asked. "It has two protons and two neutrons in its most common isotope. Let's add up their weights."

1.00758—proton
1.00758—proton
1.00893—neutron
1.00893—neutron
4.03302—TOTAL MASS OF NUCLEAR PARTICLES

"But scientist found a peculiar thing when they weighed a regular helium nucleus. The nucleus weighed less than the particles that made it up! In short, the whole weighed less than the sum of the parts."

4.03302—mass of total particles
– 4.00280—mass of helium-4 nucleus
.03022—DIFFERENCE IN MASS

"But, Dad!" Randy exclaimed. "Where did the mass go? Wait a minute . . . didn't I read something about that once? Sure! I know! Isn't the missing mass changed into energy?"

"Right! Energy to bind these particles into a single nucleus of helium. You can't just mix up a batch of protons and neutrons and come up with an assortment of elements,

you know. You need energy to hold the particles together. So part of the mass is converted into energy. You can calculate the energy by using Einstein's famous equation."

"You mean $E = mc^2$?" asked Randy.

"Yes. Most people have heard of this equation. But they don't know how to use it. This is the way."

Mr. Morrow showed Randy how to calculate the binding energy of helium-4. "Instead of units of atomic weight, let's convert our masses into grams. The question is, how much energy is needed to convert 2.01516 grams of protons and 2.01786 grams of neutrons into 4.00280 grams of helium-4. What would you do first?"

"Well—substract the actual weight of the helium-4, which would be 4.00280, from the total weight of the particles, which is 4.03302. That gives .03022 gram that's converted into energy."

"Right. Three one-hundredths of a gram. Just a tiny speck."

Mr. Morrow wrote the Einstein equation:

$$E = mc^2$$

$$\text{Energy} = (\text{mass}) \times (\text{speed of light})^2$$

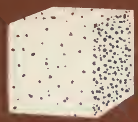
$$\text{Energy (ergs)} = (.03022 \text{ gram}) \times (30 \text{ billion centimeters/sec.})^2$$

$$\text{Energy} = 9{,}066{,}000{,}000{,}000{,}000{,}000 \text{ ergs}$$

Randy exclaimed, "That's a lot of ergs! Can you change that into some everyday units?"

Mr. Morrow said, "I need my slide rule! But let's see . . ."

He scribbled away, then studied the result and scratched his head. "I get about three million kilowatt-hours. You



If all the matter in a cube of sugar could be fully converted into energy . . .

$$E = mc^2$$

It would furnish a day's supply of electrical power for a medium-sized city.

could burn three million 100-watt bulbs for 10 hours with that energy."

"All that energy? From that little speck?" Randy asked incredulously.

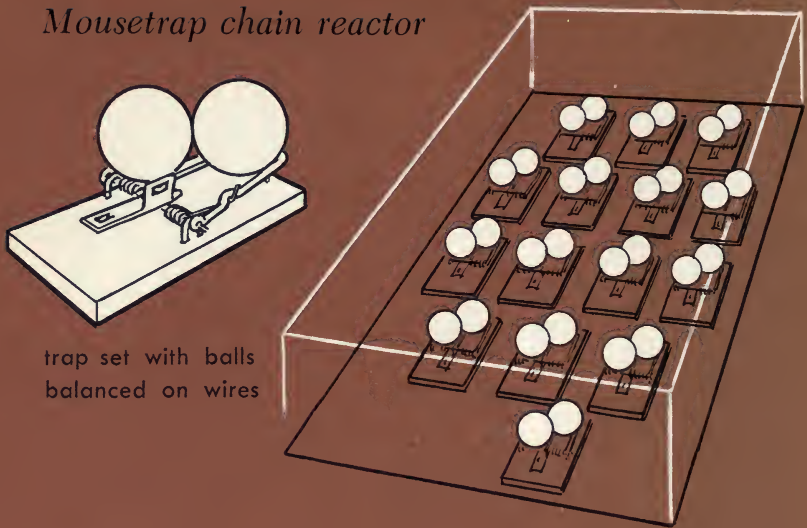
"That's right. Now maybe you've got a better idea of the fantastic power locked up in the nucleus."

Somewhere upstairs a door slammed.

"Here comes Sam," Mr. Morrow said. "Now we'll be able to show how neutrons release some of the binding energy of the atom."

Sam clumped down the basement stairs carrying a lumpy

Mousetrap chain reactor



trap set with balls balanced on wires

Each set trap represents a U-235 atom. The ping-pong balls are the neutrons to be released when the "atom" splits. A cardboard suit-box cover serves as a neutron reflector.

package in his arms.

"The guy at the hardware store said I was crazy! How about that! I said I wanted a dozen mousetraps. He tried to sell me some of those four-at-one-blow traps."

Randy said, "Good grief, you didn't get that kind, did you?"

"Nope. I told him I needed the regular type traps for a chain reaction. That's when he said I was crazy."

"Poor Sam!" Mr. Morrow laughed. "Cheer up—all scientists have to face misunderstandings."

They found that they had 15 mousetraps and 34 ping-pong balls.

Mr. Morrow explained briefly to Sam that they were going to try to demonstrate how a single neutron could cause

many uranium nuclei to fission.

"Each one of these mousetraps will represent a nucleus of uranium-235. The ping-pong balls represent neutrons."

Mr. Morrow showed the boys how to set the traps and balance two ping-pong balls on the wires of each trap.

A lot of yelling accompanied the trap-setting session. The traps seemed to take a fiendish delight in snapping unwary fingers. But at last all the balls were in position.

Mr. Morrow took one of the traps aside. "Here, fellow scientists, we have a uranium nucleus." He held up a ping-pong ball. "Here we have a slow neutron. What happens when this neutron penetrates the uranium nucleus?"

Mr. Morrow dropped the ping-pong ball onto the bait-holder of the trap. There was a loud *snap!*

The two balls that had been balanced on the trap wires sprang into the air and went bouncing away onto the floor.

"The nucleus fissions, releasing spare neutrons. Now in order to have a chain reaction, we have to use these spare neutrons to set off *other* mousetraps—I mean other uranium nuclei. There are several problems. Can you think of any?"

"We have to prevent the neutrons from escaping," Randy said. "If they go bouncing on the floor, they won't do us any good."

"Correct. The neutrons must be made to hang around long enough so that they can be absorbed by near-by nuclei. Let's see how we can solve that problem with our mouse-trap set-up."

Mr. Morrow took the cover of the cardboard suitbox and placed it over the group of traps.

"This is a neutron reflector. Neutrons that strike it will bounce back into the mass of traps."

"Do atomic scientists use real neutron reflectors?" Sam asked.

"Yes, they do," his father replied. "And they'd work with a lump of uranium, not with a single layer of atoms, like our mousetraps. Neutrons that head up or down in a real chain reaction can be captured by the uranium atoms above and below them."

Mr. Morrow had Randy cut a two-inch hole in one end of the top of the suitbox cover. "We'll drop our triggering neutron through the hole," Mr. Morrow explained.

Sam got the honor of dropping the neutron, just as his father had promised him. The ball dropped through the hole. There was a flurry of snaps as the traps inside went off.

"Whoopee!" Sam cried.

"The chain reaction is born," said Mr. Morrow.

They took the reflector off to examine the mousetrap reactor. Three of the traps were still unsprung.

"Here are three unfissioned nuclei," Mr. Morrow said. "But most of our atoms fissioned and released their neutrons."

"Then it must be easy to cause chain reactions," Sam said. "All you've got to do is get a bunch of uranium-235 and add neutrons!"

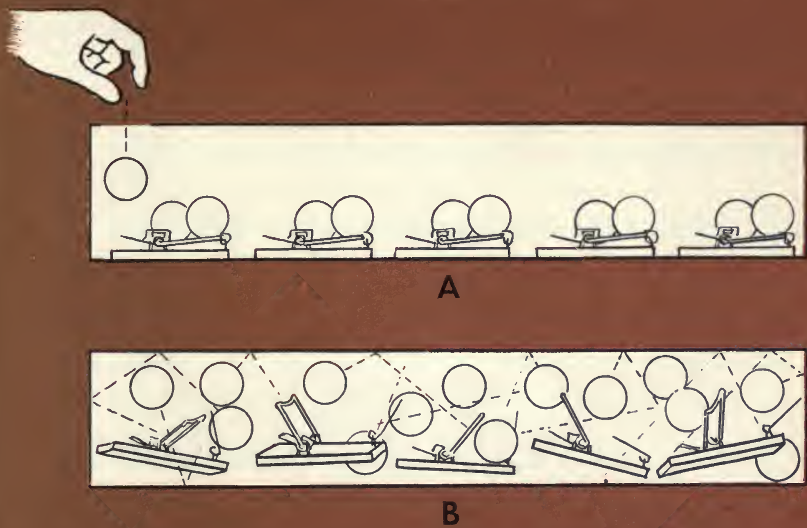
Mr. Morrow laughed. "There are a few more problems. Number one, our reaction stopped because it ran out of fuel. You've got to have enough U-235 atoms to keep the reaction going.

"Problem two involves the neutrons released by the splitting atoms. They're *fast* neutrons. But we need *slow* neutrons to keep the chain reaction going, since that's the kind U-235 likes to absorb."

"How can we slow 'em down?" Sam puzzled.

"We have to pass the neutrons through some substance that will do the trick. Imagine our suitbox filled with water. When the traps snapped, they'd throw off their neutrons.

Setting off a model chain reaction



A triggering neutron, dropped through a hole in the box in A, sets off the reaction. B shows the atoms splitting and releasing their neutrons, which in turn set off other atoms. The reaction eventually stops because it runs out of fuel.

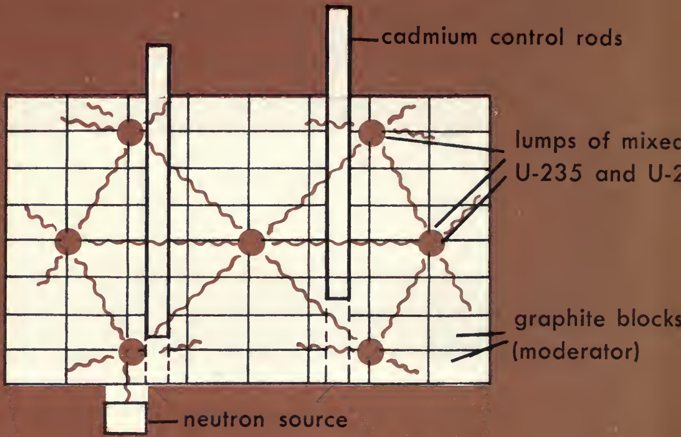
But the neutrons would be slowed down by passing through the water."

"Is that how they slow down real neutrons?" Sam asked.

"Real neutrons are slowed down by passing them through a *moderator*. The moderator *can* be water—light water or heavy water. It can be graphite, the stuff that makes pencil leads, or paraffin like your grandma puts on top of jelly. A good moderator doesn't absorb neutrons itself. The neutrons collide with the atoms of the moderator and are slowed down."

Mr. Morrow drew a sketch of a simple kind of chain re-

Lattice pile reactor—first working type



Trigger source of slow neutrons starts fission process in one lump of uranium. Fast neutrons freed by fission travel through graphite moderator, are slowed down, and cause fission in adjoining lumps. Control rods can absorb neutrons and stop reaction.

actor, telling the boys that this was the first type of atomic pile to continue working, once it had been started.

"This kind of device is a lattice pile. The moderator is in block form, stacked up in a big cube. Here and there in the cube are little spaces for lumps of uranium. A source of neutrons near the bottom of the pile starts one lump of uranium to fissioning."

Randy said, "I see! The neutrons from the fissioning atoms travel through the graphite to the next lump of uranium, and cause *those* atoms to fission. And the thing keeps working chainwise!"

"That's the idea. The pile will keep working by itself —that is, the chain reaction will be self-sustaining—if most of the neutrons are captured by other nuclei, instead of

being lost or absorbed by some other substance."

"I understand," Randy said. "Suppose that each splitting atom released two neutrons that could be grabbed up by other atoms. The reaction would start, and go faster and faster and faster—"

"Wait!" Sam said. "How can we get it to stop?"

"Cut off the supply of neutrons," Mr. Morrow said.

He explained that several kinds of material, like cadmium metal, for example, tend to soak up neutrons. "So if you make a rod out of cadmium, and have openings in the reactor so that you can move cadmium rods in and out, you can control the flow of neutrons and the speed of the reaction."

"You've sure gotta control the reaction," Sam said darkly. "Otherwise, the reactor might—might blow up!"

Mr. Morrow corrected him. "Not blow up—but it might melt or burst apart. Reactors produce heat. Really efficient reactors get tremendously hot and require tons of cooling water to keep them safe. It's this heat energy produced by nuclear fission that can be harnessed to do useful work."

"Atomic power!" Randy exclaimed.

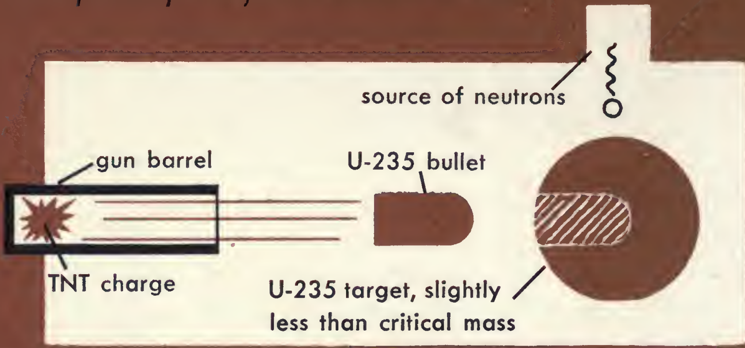
"Are reactors good for anything else besides making heat?" Sam asked.

"The neutrons are useful in making radioisotopes. Bombard ordinary elements with neutrons, and you make them radioactive. If you put a piece of gold into an operating reactor, the gold would become radioactive. Radioisotopes have many uses."

"That's a second use for reactors," Randy said. "Are there any more?"

Mr. Morrow said, "Reactors are important research tools, of course. You can make heavy elements in a reactor. Plutonium, the element used in atomic weapons, is made in

The principle of the atomic bomb



Here is one way an atomic bomb could be constructed. At one end of the case is a large target-like lump of U-235. It is slightly less than critical mass. If a chain reaction started in the target, it would quickly die out because too many neutrons would be lost by flying off the surface of the lump. At the other end of the case is a device resembling a gun, containing a U-235 bullet. The mass of this bullet, plus that of the target, is *greater than* critical mass. When the bullet penetrates the target, a burst of neutrons triggers off the bomb. In a fraction of a second, most of the atoms split, releasing their energy all at once.

one type of atomic reactor:—there are several types."

"Something I meant to ask," Sam broke in. "How is a chain reaction in an atomic pile different from an atomic bomb?"

His father asked him, "Did you ever open up a cap from your cap-gun and set a match to the little pile of gunpowder?"

"Sure. It just burns. No bang or anything."

"That's because the molecules of gunpowder are breaking down a few at a time. Now if you set them all off at once by tapping the cap, you have an explosion. And if you have the gunpowder closely confined—like it is inside the thick

paper cylinder of a firecracker—the explosion is even bigger."

"You mean it's the same for an atomic bomb?" Sam wanted to know.

"Very similar. In the reactor, the atoms in the uranium lump are mixed U-235 and U-238. The chain reaction proceeds fairly slowly. In a bomb, the material is practically pure U-235 or plutonium, which splits like U-235 does. If you get a lump of fissionable material of a certain size—called a critical size—and feed it a neutron, most of the atoms will fission within a fraction of a second, releasing their energy."

"I see," said Sam. "Release the energy slowly—you get heat. Release it all at once, you get an explosion."

"And you can see how it all depends on neutrons," Mr. Morrow said. "Engineers that design nuclear reactors are always worrying about neutrons."

"I don't see why," Sam said. "The U-235 splits, it gives off neutrons, the neutrons go through the moderator, they split other uranium atoms. What could be simpler?"

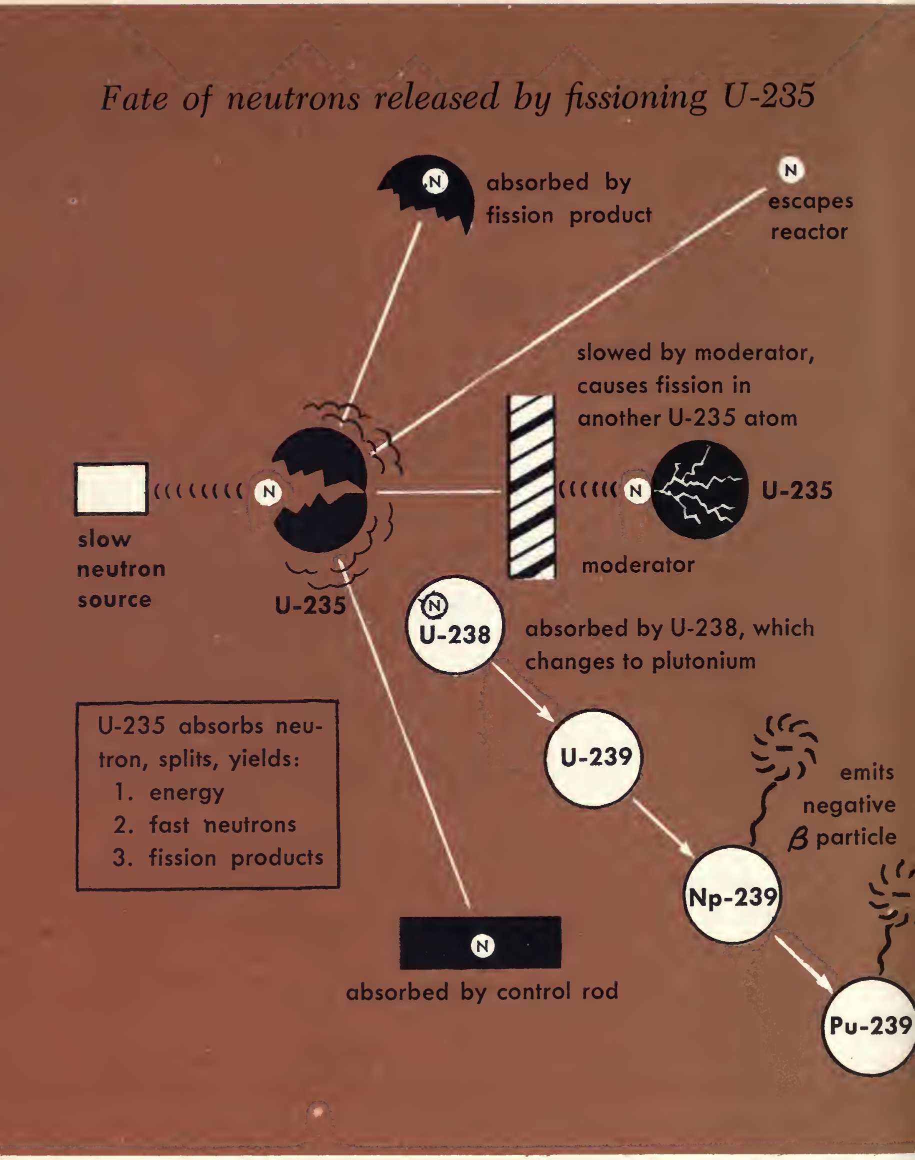
"Unfortunately, there's more to it than that. For one thing, the neutrons will leak out unless the reactor is carefully designed. For another thing, the pieces of the split nuclei—the fission products—keep piling up. Some of these fission products act just like the cadmium control rods—they absorb neutrons. If too many of the neutrons are absorbed, the chain reaction stops."

"What can be done about it, Dad?" Randy asked.

"The fuel unit that's been 'poisoned' by fission products has to be removed and purified. A fresh unit replaces it in the reactor."

"I wish we could see a real reactor," Sam said wistfully.

"I'm trying to arrange for a visit," his father said.



"Wow!"

"I've been talking to a friend of mine out at Argonne

National Laboratory. You could really see atomic energy in action out there."

Randy said, "When do you think we might be able to go?"

"When shool lets out in a few weeks, we'll see. Meanwhile, I've sent for some booklets on atomic energy from the A.E.C. in Washington. It might be a good idea for you to read about the different reactors and find out how they work."

"Maybe we could build some models!" Randy said.

"Good idea. Build the models, then we'll take a look at the real thing. You boys will be nuclear engineers yet!"

CHAPTER **10**

Atoms in action—model reactors

THE DAYS went by, and schooldays finally came to an end. Randy and Sam haunted the mailbox, waiting for the booklets on reactors.

Finally a package arrived. It was a big manila envelope with the return address, U. S. Atomic Energy Commission, Washington 25, D. C.

"The stuff!" Randy shouted. "It's here!" He began shuffling through the contents of the envelope while Sam stood impatiently by.

"Let's see that one," Sam said. He took a booklet entitled *Electric Power from the Atom*. It was full of diagrams and drawings of atomic power plants.

"Look how simple this is," Sam said. "You get electricity by powering a generator with a steam turbine. In an ordi-

nary power plant, the steam comes from water heated by coal. In atomic power plants, the water is heated by splitting atoms."

"Why don't you make a model of this power plant?" Randy suggested.

Sam thought it over and agreed. Randy found it more difficult to choose his own project. Finally he said, "This Oak Ridge reactor would make a good model. And it would show how a reactor can make plutonium and radioisotopes at the same time."

"I'll bet I finish my model before you get yours done," said Sam craftily.

"Is that so? You'll be coming around wanting me to help you five minutes after you get started."

The boys finally decided that they'd work separately—Randy at the workbench and Sam in the bedroom.

"No fair using any fancy stuff to build your model," Sam said. "Just what's around the house."

"Okay," Randy said. "Let's go."

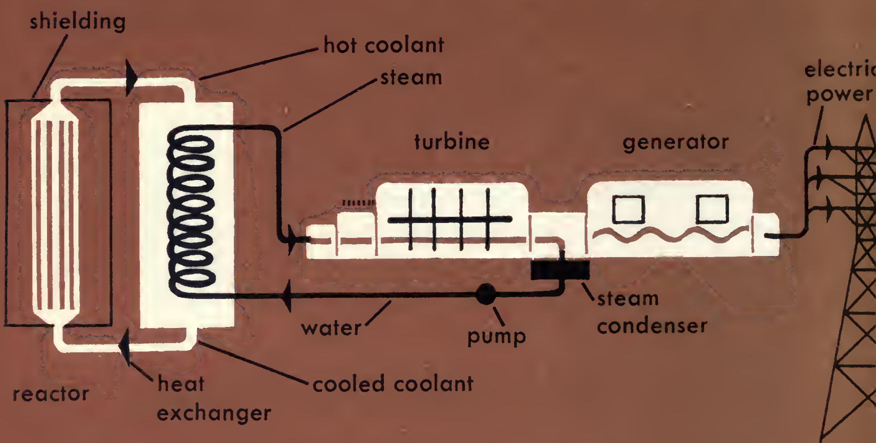
Sam studied the illustration of the atomic power plant. It was a simple diagram without much detail, so Sam felt that he could use a little creative imagination in engineering his model.

"Four main parts," he muttered to himself. "Reactor, heat exchanger, then the turbine and generator. The turbine has a condenser for turning the steam back into water, and a pump for pumping the water back to the heat exchanger."

Sam decided to make his units out of tin cans, since his reactor would not be a working model but merely a representation.

The boy went into the kitchen, looking for appropriate cans. He found a fruit juice can, half full, in the refriger-

How an atomic power plant works



Heat generated by the splitting atoms in the reactor is picked up by the liquid coolant and circulated to the heat exchanger. Water in the heat exchanger coil is turned to steam and used to run a turbine. The turbine operates the electrical generator to produce electric power.

ator.

"Just the thing for the reactor," he said, and poured the juice into a pitcher. Unfortunately there weren't any more opened cans available.

"But I guess Mom would want to help the cause of science," he decided. He opened two cans of peaches and a can of mushroom soup. The food was placed in bowls, and the cans washed and stripped of their labels.

Sam had neatly removed the can lids and saved them. He intended to make each unit so that it could be opened and inspected.

Sam began construction of the first unit, the reactor. The reactor would need fuel units and control rods, and a cir-

culating system for the cooling liquid that would be sent to the heat exchanger.

He got an ice-pick to punch holes in the cans, and some of those spread-legged paper fasteners to fasten his units to a heavy cardboard base. He also got his father's tin snips to help cut the metal.

The reactor can was flattened slightly along one side, then cut in half the long way with the flattened side making the bottom. Sam punched two holes in the bottom and mounted the can on the cardboard with a couple of paper fasteners.

The coolant in real power reactors was circulated through a system of pipes. And Sam faced a dilemma here, for he had no tubing with such a small diameter.

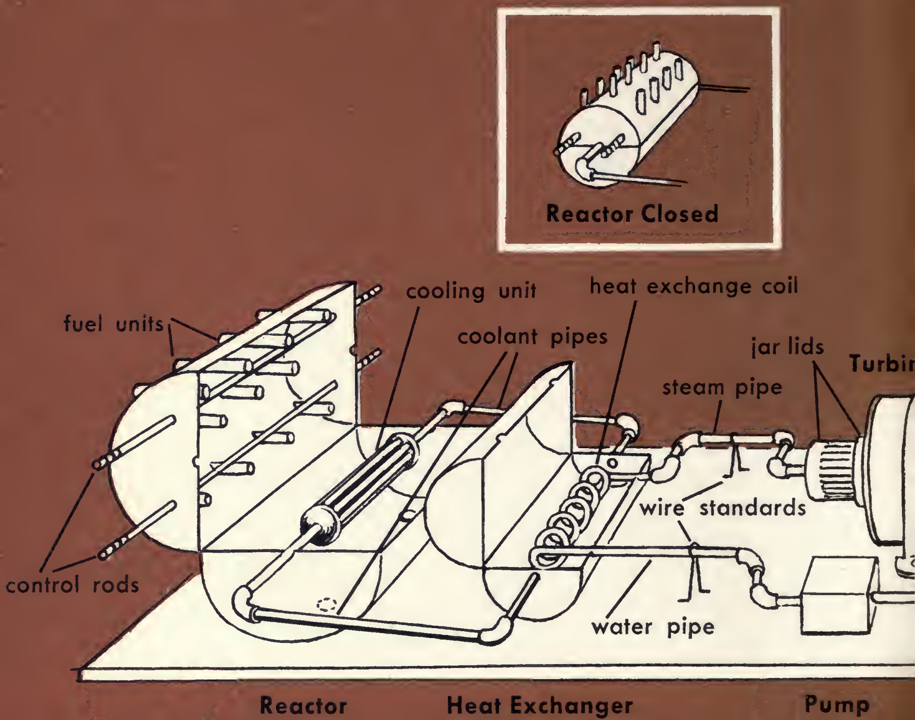
He thought about it for awhile, then went rummaging in his mother's food supplies. Finally he found what he was looking for—a box of long macaroni.

"Just like pipe!" he said smugly. "And I'll even be able to bend it if I soften it in boiling water a little. I'll paint it with aluminum paint when I'm done, and it'll really look sharp!"

The cooling unit was made out of macaroni, glue, modeling clay, and a couple of large-diameter buttons. Sam mounted the unit in the bottom half of the reactor with some liquid solder. At the place where the piping left the reactor, Sam installed fittings of larger-diameter elbo macaroni to receive the connecting pipes from the heat exchange unit.

Next, the boy turned to the top half of the reactor. He punched two rows of holes in the upper curved surface to admit the fuel units. He made these out of two-inch lengths of macaroni, painted red with water colors. Each fuel unit was firmly wedged into its hole and fixed with liquid solder.

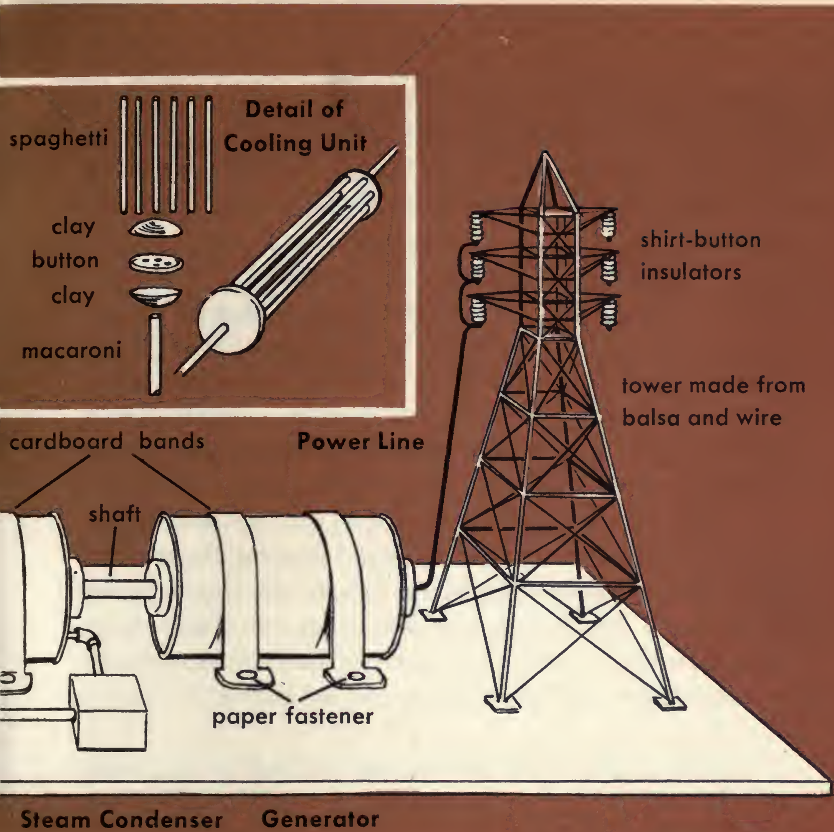
Sam's model atomic power plant



The units of Sam's power plant are made from large tin cans. The reactor and heat exchanger units were cut in half by first removing the lids, cutting with tin snips, then soldering the halved lids back on with liquid solder. The piping is made from macaroni, the joints from elbo macaroni. If elbos are softened in water, fitting is easier.

The control rods were longer lengths of macaroni, painted with black stripes and inserted horizontally from the flat side of the can.

"The whole inside of this can ought to be filled with



For a more realistic appearance, finish with aluminum paint. Sam painted his macaroni fuel units red, his control rods white with black stripes. The heat exchange coil was made from macaroni, softened in boiling water, then coiled around a cardboard form and permitted to harden. The whole power plant was fastened to its base with spread-legged paper fasteners.

moderator," Sam thought. But he decided that the moderator would have to be imagined, since he didn't want to hide the details of the reactor. He placed the top half of the can in place, and the reactor was finished.

The heat exchange unit was next. Sam also cut this can in half lengthwise and mounted the lower half on the cardboard. The heat exchange unit was connected directly with the reactor cooling system through lengths of macaroni pipe.

Then Sam tried to figure out how to make the heat exchange coil that would bring water into the unit to be converted to steam. He learned how to coil the macaroni piping after a trial and error session. He softened the macaroni in boiling water, then coiled several lengths of it around a cylindrical cardboard core from a roll of paper towels, and put it in a warm place to dry.

Next, Sam mounted the turbine unit can. He did not cut this unit in half, since he didn't intend to show the interior of the turbine. At one end of the turbine, he fixed a small pillbox which would represent the steam condenser. Next to the condenser, he mounted another small box to represent the pump that would return the water to the heat exchange coil.

The coil was mounted in the heat exchange unit, and connected directly with the turbine. Sam braced the connecting lengths of macaroni with small wire standards fastened to the cardboard base.

The can that served as a generator was mounted in front of the turbine and connected to it with a macaroni shaft.

As a final touch, Sam worked up a tiny power pole out of some wire and narrow sticks and connected it to the generator with a thread.

"That looks swell," Sam said, inspecting his finished power plant. And it was true. The cans were shiny and neatly mounted. The lids that had been removed were neatly soldered back into place. The macaroni was completely disguised by its coat of aluminum paint.

There was just one thing missing—labels for the units. Sam crept into his father's study and pecked out a few words on the typewriter. When the labels were glued in place, the model was done.

"Bet I beat Randy!" Sam laughed to himself.

Curiosity began to get the better of him. What did Randy's model look like? Of course he really should wait until Randy invited him to inspect it. But on the other hand . . .

Noiselessly, Sam moved to the basement steps and opened the door. He listened. There was no sound from the Morrow Atomic Laboratory below. Sam began to inch his way down.

No one challenged him. Randy must be out hunting for some part for his model. It would be a perfect opportunity to sneak a look. Sam stepped forward—

Everything went black.

"Yow!" Sam cried, struggling to remove the hands that had clamped over his eyes from behind. A knee was poked into the small of his back.

"So! Spies!" said a grim voice. "Take that!"

"Hey, take it easy!" Sam wailed. "I'll go quietly."

The hands were removed from Sam's eyes. Randy laughed. "You flunk, Junior Spy Scout. Just remember that the security division of the Morrow Atomic Lab is always on guard!"

"Aw. I just wanted to see how you were comin'," Sam mumbled.

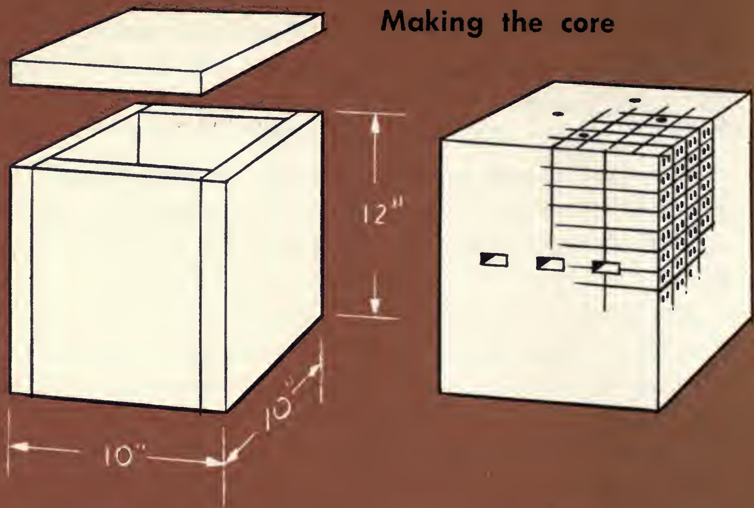
"I'll show you," Randy said good-naturedly. "No need to come sneaking around." He displayed his partially completed model.

"Gee," breathed Sam.

Randy had realized from the outset that his model would

Randy's model reactor

Making the core

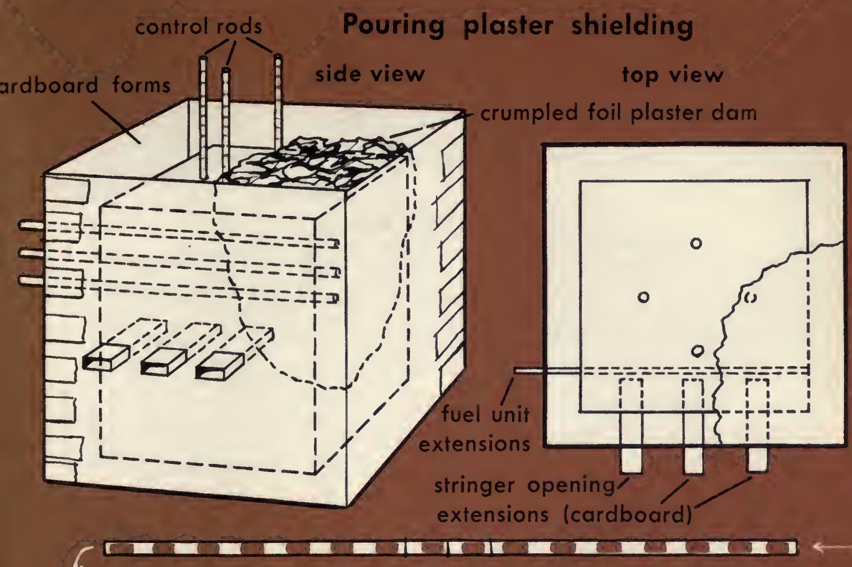


The graphite core of the reactor is made out of pieces of wood, cut to the dimensions shown, nailed together, and sanded. The openings for the stringer-trays are cut with a keyhole saw. Several fuel element openings are drilled through front and back to hold fuel unit tubes, made from large soda straws. Paint core gray and draw on block markings and dummy fuel openings with India ink. Mark only the section that will be exposed.

take longer to make than Sam's. And the deeper he got into his project, the more fascinated he became. He determined to make his reactor as complete as possible.

The unfinished model standing on Randy's workbench was about 10 inches square and nearly a foot high. Sam could see the exposed central portion consisted of a cube of wood that had been painted gray and scored off into sections.

"This gray block represents the graphite moderator," Randy explained. "Horizontal openings go all through the



Fuel unit, made from two spliced soda straws. Fuel slugs made from pressed aluminum foil.

Brace forms carefully with wood blocks before pouring. Tape waxed paper to "cutaway" face to protect surface. Pour plaster up to lower edge of cutaway; insert firmly-packed foil dam. Pour rest of plaster. Jiggle extensions slightly before plaster hardens completely to make removal easy.

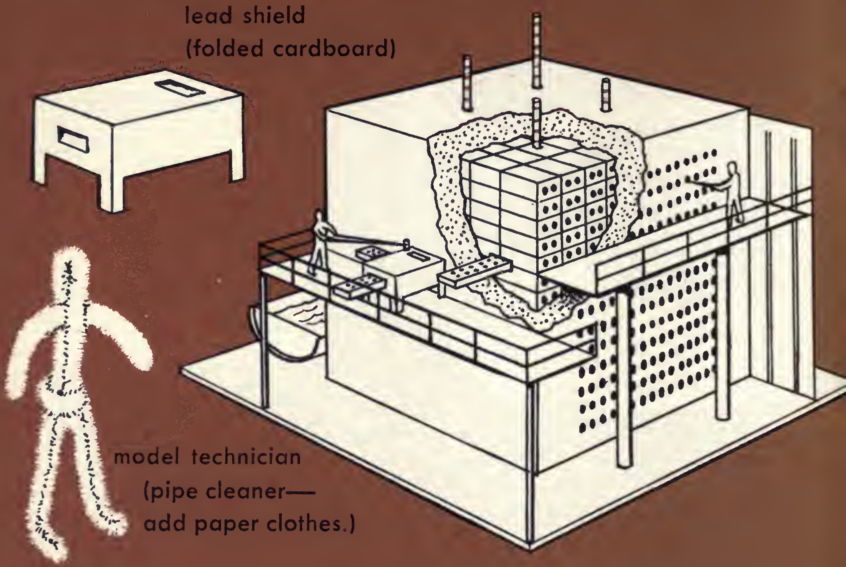
real reactor. The fuel goes in there. Vertical openings from the top of the pile serve for the control rods."

Sam peered at the fuel openings. "You've only drilled a few of these all the way through. The other holes are only painted on."

Randy shrugged. "A real reactor has hundreds of fuel openings. I have a few working fuel openings and the rest are dummies."

Randy showed Sam the model fuel units. In a real reactor, the slugs of uranium metal would be enclosed in an alumi-

Completed cutaway model



Dummy fuel element openings are drawn on with India Ink. Elevator and catwalk are made from cardboard, wire, wooden dowels. Water tank for spent fuel elements is made from tin can, cut in half. Control rods are macaroni, painted with red and white stripes.

num housing.

"I used soda straws, and made my little slugs out of rolls of Mom's aluminum foil. See, you feed the little slugs in this end of the housing and push the thing into the reactor. The fuel is part U-235 and part U-238. The 235 splits and furnishes energy and neutrons. The 238 turns into plutonium."

"Then what?"

"After awhile the slugs of fuel are 'spent.' That means the reaction has gone as far as it can efficiently go. The spent

slugs are pushed out the back of the pile."

Randy poked into one of the soda-straw fuel units with a length of narrow copper wire. Out fell a number of the tiny "uranium" slugs.

"As these spent slugs fall out the back of the reactor, you keep feeding fresh slugs in the front. The spent slugs lie around in a tank of water in back until all their neptunium is converted into plutonium. Then they go to a remote-control chemical processing plant."

"You going to make a water tank, too?"

"Sure. Out of a sliced-open can, mounted like a trough. Have a seat now, and watch me pour the concrete shielding for the reactor."

"Real concrete?" Sam gasped.

Randy grinned. "Plaster of Paris. See this little stack of forms? I worked them up out of cardboard with waxed paper taped to it."

Randy began to set up his forms around the "graphite" cube, fastening them with cellophane tape and bracing them with pieces of wood.

Only part of the model would be shielded, since Randy intended one side to show a cutaway view of the interior of the pile. At the rear of the reactor, where the fuel slugs were ejected, he installed temporary lengths of soda straw in the forms so that the fuel ejection openings would penetrate the shielding.

Various other openings in the reactor were taken care of as well, such as the channels for the control rods, and the holes where trays of isotopes were inserted from the side.

"Now that we've got the forms set up, let's mix the plaster."

Randy used slightly warm water so the plaster would set quickly. As he poured it into the form, he had Sam work

a pencil up and down in the mixture to eliminate air bubbles and make sure the liquid plaster penetrated to each corner of the form.

Crumpled aluminum foil served to hold back the plaster at the points where the interior was to be exposed. As the plaster covering reached the top of the reactor, Randy placed a few pieces of waxed paper over the exposed corner of the graphite to protect it. He dammed the plaster with more crumpled foil at this point, and finished the top layer of shielding. Finally, all of the plaster was in place.

"Now we'll leave those forms up for an hour or so and let the plaster harden. I'll get busy making some of this other stuff."

The control rods of this type of reactor were actually made out of boron steel. "But I suppose I could use pencils or something," Randy said dubiously.

"Try macaroni," grinned Sam, and told how this unusual construction material had worked for him.

"Sam, boy, you're a genius. Now let's make some stringers."

"What're they?"

"Long blocks of graphite, like trays. There are holes in them for putting in elements that you want to make radioactive. The stringers are pushed into the reactor from the side. I made some openings for them here."

The boys made the stringers out of balsa strips from an old kite. These were sanded, then small holes were bored in them. Randy let Sam paint the stringers the same silvery-gray color as the graphite cube. The interior of the holes was painted black.

Sam suggested that he could mold some little radioisotope cans out of aluminum foil. "They'd be solid, not hollow like real cans," he apologized, "but you could put

'em in the holes in the stringers and they'd look like the real thing."

"Sure. Go ahead."

More balsa wood, some cardboard, and glue went into the making of the portable lead shield that went around the stringer openings.

Then Randy made a little elevator platform that would operate up and down the fuel-insertion side of the reactor.

After a while, it was time to remove the forms from the plaster shielding. There was very little sticking, thanks to the waxed paper. Randy easily smoothed down the few rough spots at the joints, making the shielding smooth and neat. The cutaway edge of the shield was irregular, thanks to the crumpled foil.

On the fuel ejection side, Randy trimmed off the straw tubes level with the face of the plaster. The dummy holes, that did not actually penetrate the pile, were drawn on the shielding with India ink.

Randy installed the elevator and a catwalk for the isotope removal section. He attached the water tank at the back of the reactor.

"I'm going to work up a little model conveyor, too," Randy said. "I can do it with some more cardboard. The conveyor is for taking the fuel slugs from the water tank to the processing plant where the plutonium and fission products are separated from the uranium."

Randy sat back to admire his work. "Doesn't that look swell?" he asked.

The boys' mother came down just then to see what they were doing. She looked over Randy's model reactor.

"It still needs one thing, dear," she said.

"What's that, Mom?"

"Some little figures to show the scale of the model. You

need a tiny little technician working on the reactor."

Mrs. Morrow showed Randy how easy it was to make miniature men out of colored paper and thin wire. They simply formed the wire into "stick-man" figurines, and used a bit of modeling clay to make the heads, about the size of those of a match. Small bits of paper were pasted to the wire to simulate clothes.

The tiny technicians were dressed in white coveralls. Randy placed one on the isotope catwalk and another on the elevator, working on the fuel elements.

Meanwhile, Sam had brought down his model. He now placed it beside his brother's masterpiece.

"Which one do you like best, Mom?" Sam asked.

"I think both of you boys have done a marvelous job," Mrs. Morrow said diplomatically.

Sam said anxiously, "I sure hope Dad thinks so. Otherwise, we might not get to go to Argonne."

"You don't have to worry about that," Mrs. Morrow laughed.

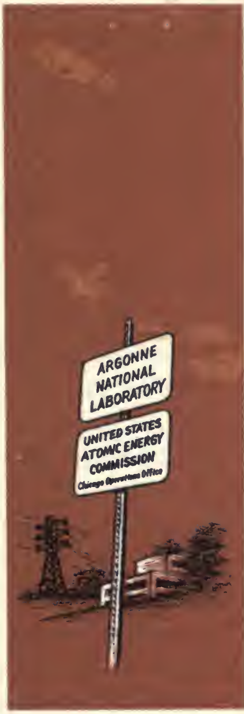
"We—don't?" Randy hesitated.

"That's what I came down to tell you," his mother explained. "The public relations department of the lab just called your father. Since he's downtown at the library, I got the message. You boys are going to make your visit next Tuesday."

Bedlam broke loose. Mrs. Morrow finally escaped after being hugged only eleven times.

CHAPTER 11

Boys among the atoms



"Do YOU know what impresses me the most about this country, Dad?" asked Randy. They were on the highway, driving toward Argonne National Laboratory.

"What's that, son?"

"Well, Chicago is a big city. And all around it you find lots of smaller cities and towns—and in between them, lots of farms. But in here—there's nothing! It seems so funny to find open country like this close to a big city."

"It's a forest preserve," Sam said. "Can't you read the signs?"

They drove over a bridge spanning two canals and a little river. Coal barges were moving up the canal from the Mississippi toward Chicago.

"You wouldn't expect them to build a large atomic installation in the midst of a city, Randy," his father said. "And yet they need trained people from Chicago to operate the lab. So they located it here, about 25 miles outside the city."

Suddenly there was a double sign:

ARGONNE NATIONAL LABORATORY

UNITED STATES ATOMIC ENERGY COMMISSION

Chicago Operations Office

They swung off on a side road into a rolling section. Ahead, among the low hills, they could see clusters of gray and red buildings.

They drove through an ordinary gate in an ordinary cyclone fence. "No guards?" asked Sam, disappointed.

His father laughed. "Were you expecting a blockhouse with bazookas?" They parked the car and headed for Building 2, the administration building.

"We'll meet my friend, Mr. Bentson, here. He's arranged this trip for *me*, actually, but if you guys tag along part of the way—maybe no one'll make a federal case out of it."

"I getcha, Dad," Randy said.

"High school groups can take a guided tour of Argonne," Mr. Morrow explained, "but individual youngsters don't as a rule. I want you guys to behave like men. No touching anything, no sneaking off to look at things by yourself."

The boys vowed they'd stick close to their father.

"There's one more thing," Mr. Morrow said. "Sam, I'm afraid some of the buildings are off limits to those under 14."

"Aw," Sam began.

"No helping it," Mr. Morrow said. "You'll have to wait in the car. But console yourself by remembering that you get to see most of the stuff, anyway."

"All right," said Sam mournfully. "I'll do it, but I'm not happy about it."

They moved into the reception hall. It was a brightly lit room full of bulletin boards and visitors. Mr. Morrow went over to talk with a young woman at the information desk, and the boys looked around.

Near the ceiling was a neat sign that said: *Do Not Discuss Classified Information in This Area.* The bulletin boards held notices of meetings, discussion groups, concerts and art shows, conventions, and other events. Spotted here and there were safety posters.

In a moment, Mr. Morrow returned. He told the boys that Mr. Bentson would meet them in a few minutes.

"I thought it would be scary," Sam piped up.

Randy laughed, "Why, for Pete's sake?"

"Well, you know—an atomic laboratory. Top secret stuff. But I don't see any guards or—or anything."

Mr. Morrow said, "Argonne has a security force. They're like the watchmen at big industrial plants. You will find guards around some of the buildings where classified work is being carried on. But a lot of the work done here isn't secret at all. And that's what you're going to see today."

A white-haired, youngish looking man came up and shook hands with Mr. Morrow. He had very pale blue eyes and very dark frames on his eyeglasses. Randy was foolishly reminded of a panda as his father introduced Mr. Bentson.

"So you're the lads who want the fifty-cent tour, eh?" the man said cordially. "Glad to know you. We'll go out and take your car."

"Couldn't we just walk around?" Sam asked.

Mr. Bentson laughed. "Your feet would get pretty tired. You'll see that we've got quite a place here!"

In the car, Mr. Bentson told them a little about the history of Argonne. How it was operated by the University of Chicago under a contract with the Atomic Energy Commission.

"But we're really an independent outfit. You'll find that the atmosphere around the place resembles that of a university more than that of a factory or military base. One director once said that all we lack is a big-time football team!"

Both boys laughed.

"Smash that line, Argonne!" Randy said. "Smash it, if it takes a billion electron volts!"

This time it was Mr. Bentson's turn to laugh. Then he told them that there were several thousand people working at the laboratory—not only scientists and technicians, but office people and maintenance workers. Argonne had its own water works, electrical distribution, and sewerage system, since it was located away from other towns.

Sam glanced out the window at the countryside. "Golly. How far are we going, anyway?"

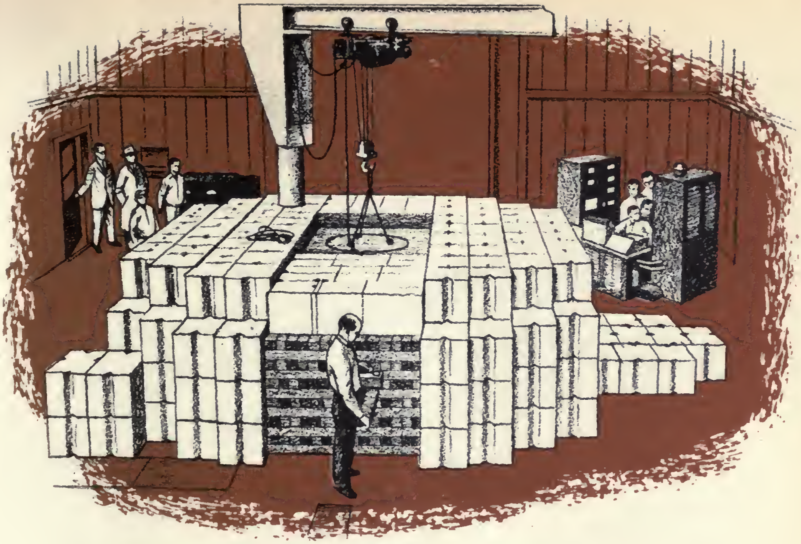
"Still interested in walking?" Mr. Bentson smiled. "Our lab grounds are really a fair-sized forest preserve. Watch for the deer."

"The *what?*"

"Deer. Chinese white ones. They were released in here to give the place a picturesque air. Sometimes they come right up to the road. Turn here."

The car swung into a side road that led toward a cluster of prefabricated buildings.

Mr. Bentson said, "The first thing we're going to see is the Argonaut. This is our student training reactor. Young



A group of students was using the Argonaut reactor.

men from all over the world come to Argonne to study at our International School of Nuclear Science and Engineering."

"How did the Argonaut get its name?" Randy asked.

"ARGO is for Argonne. The rest of the name comes from the initials of Nuclear Assembly for University Training."

They pulled up to one of the building and got out. As they entered, Mr. Bentson greeted the scientist in charge. Since a group of students was using the reactor, the Morrows and Mr. Bentson stepped back to watch.

Seen from the side, the Argonaut resembled nothing so much as a stack of concrete blocks with a crane dangling overhead. Near one corner was a control console with the students and their instructor clustered around it. A large red light on top of an instrument rack was flashing.

Mr. Bentson told the Morrows that the Argonaut was an inexpensive reactor that universities could install. "It only costs about $100,000," he said.

"Here's what a fuel element looks like."

"Only!" Randy exclaimed.

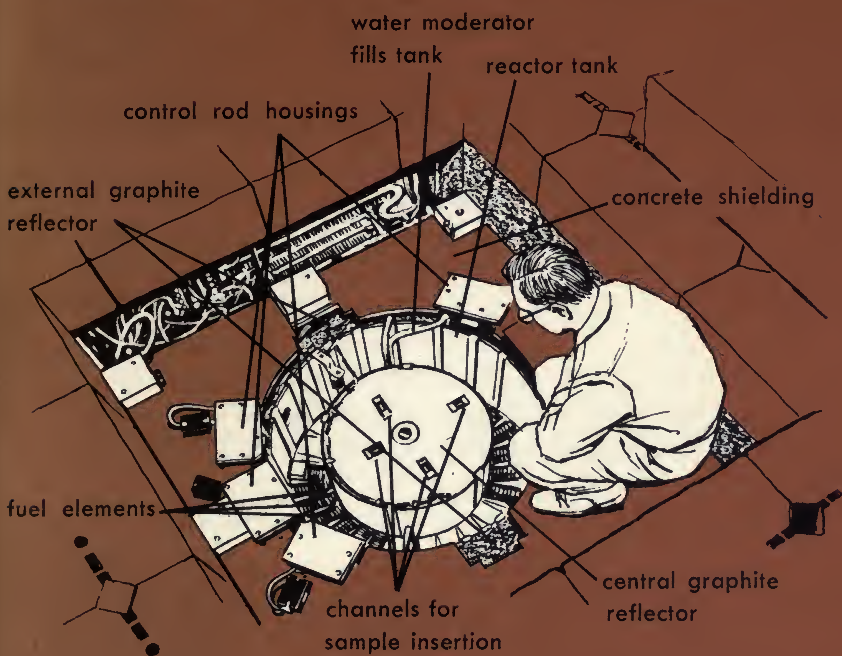
Mr. Bentson went on: "You can see the concrete block shielding around the outside of the reactor. Inside this is a cube of graphite five by five by four feet. Come over here—you can see one side of the cube."

They all moved over to the back of the Argonaut. Here a face of the graphite was exposed. Mr. Bentson told them that some of these graphite stringers were removable.

"Inside the graphite cube is the heart of the reactor. It consists of a double-walled tank. In the outer part is ordinary light water as a neutron moderator. In the inner part is a graphite neutron reflector about two feet in diameter. The fuel elements go down into the water-filled part. Here's what a fuel element looks like."

Mr. Bentson turned to a workbench. On it was an object about four inches square and two feet long. It resembled a sandwich made of seventeen plates of metal. There was

Looking into the central core of the Argonaut



The protective plug of heavy concrete has been removed, and the student scientist is examining the heart of the reactor.

space between each of the plates for the moderating water to flow.

"This fuel element is made of aluminum with uranium oxide dispersed in it. The Argonaut has less than eight pounds of U-235 in it. The neutron source is made of antimony and beryllium."

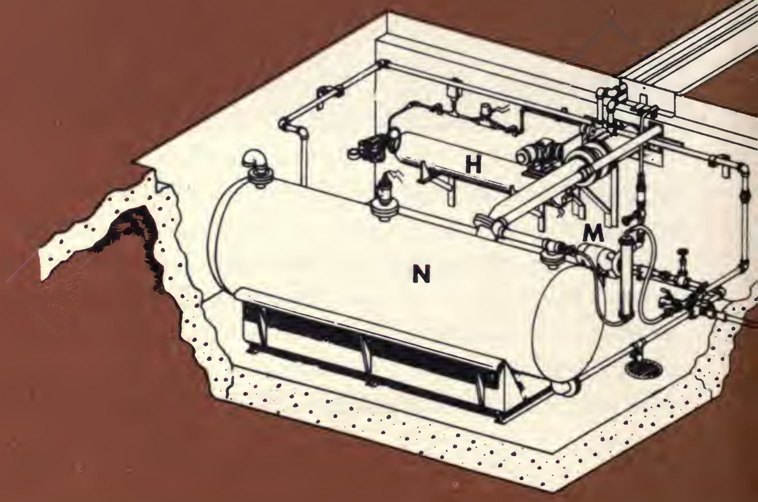
"Look!" cried Sam suddenly. "They're moving the crane!"

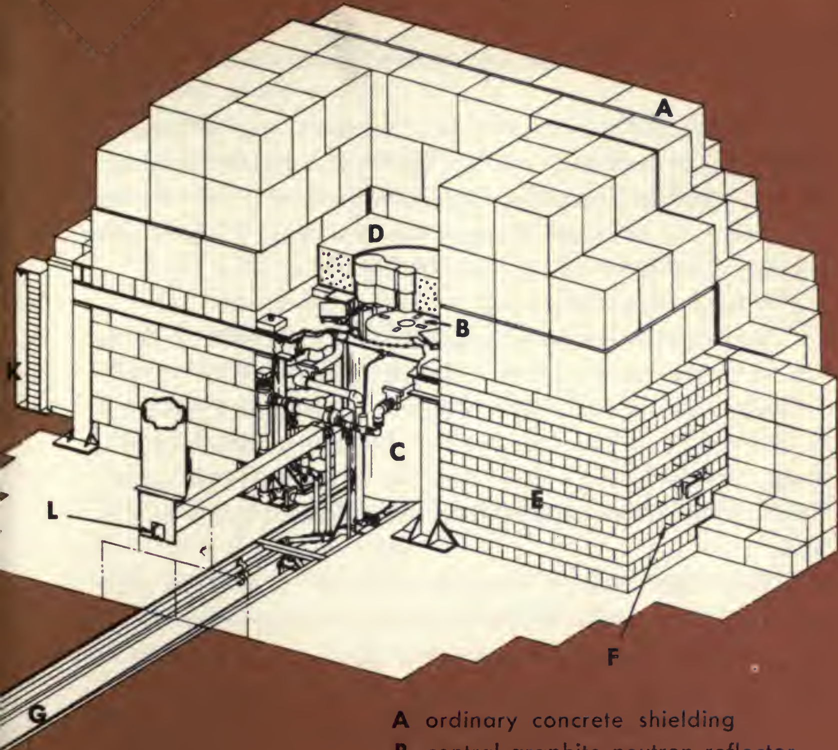
It was true. The little overhead crane had begun to raise the heavy concrete slab plug that closed the core of the reactor.

"They probably went to remove one of their experiments," Mr. Bentson observed. "The central graphite reflector has several channels in it where you can insert samples for irradiation with neutrons."

He explained that the Argonaut could be used for a number of purposes. It could test the properties of fuels and moderators. It could be used as a source of neutrons to irradiate substances and produce radioisotopes. It could be used as a calibrating source for radiation detection instruments. The decay of nuclear particles could be studied with the Argonaut. Neutrons and their reflectors could also be studied.

"One of the best things about the Argonaut is its safe





Cutaway view of Argonaut reactor

A ordinary concrete shielding
B central graphite neutron reflector
C main reactor tank, with fuel and water moderator inside
D heavy concrete shield
E graphite thermal column slows down neutrons escaping from reactor
F graphite stringers for inserting experiments
G lines leading to dump and storage tanks
H nitrogen gas cylinder
J Argonaut water supply
K facility for testing shields
L horizontal beam hole and stringer
M water pump
N dump tank

operation. This makes it particularly good for use in universities."

"What kind of safety devices does it have?" asked Randy.

"Well, first are the six control rods that regulate the speed of the reaction. These are cadmium plates that can be dropped into the core to stop the reaction. To turn the reactor off, as it were."

"By absorbing the neutrons," Randy nodded.

"Then another device dumps the moderating water. This would also cause the reaction to stop. Do you know why?"

"Sure," Randy said. "Because then the neutrons given off by the splitting uranium wouldn't be slowed down by the moderator. They'd be fast neutrons, and the U-235 nuclei wouldn't be able to capture them. The chain reaction would stop."

"That's right, Randy," said Mr. Bentson. "You know your stuff. The final safety device is a tank for pumping nitrogen gas into the reactor. Nitrogen is a good absorber of slow neutrons, and it would stop a chain reaction, too."

"What was that red light on top of the instrument rack?" Sam asked. "The one that flashed and turned round and round like the light on a squad car? It went off when the crane started to lift the lid."

"That's a safety light," Mr. Bentson said. "It goes on when the reactor is in operation. There's a photoelectric cell connected to it. You know what that is, don't you?"

"Sure," said Sam, "an electric eye."

"That's right. If somebody climbed up on top of the reactor while it was going, that light would pick the person out and stop the reactor."

As the concrete plug was lifted by the crane and laid to one side, the students swarmed to the top of the reactor, monitoring devices in their hands.

"This'll be a good time for us to look at the control console," Mr. Bentson said.

The Morrows and their guide moved over to the console, the switchboard that operated the Argonaut. The boys stood and stared. On either side of the console stood racks of instruments.

"Quite a lot of equipment, eh, boys?" their father asked.

"Gee, yes."

Mr. Bentson said, "These indicators and graph sheets on either side show what's going on inside the reactor."

Randy pointed to one very large button. Its label said simply, *Scram.*

"What's that for?"

"To stop the reactor in an emergency. It activates all of the safety devices at once."

It was time for the Morrows and Mr. Bentson to move on to the next facility. But Randy held back a moment to watch the students.

"Come on, Randy," his father urged. The boy came along slowly.

"Sorry, Dad. I was just thinking. Those guys in there—"

"What about them?"

"There they are, working with atomic energy. And they're only a few years older than *me!*"

"You'll be working on an Argonaut yourself someday, Randy," smiled Mr. Bentson. "Come on—it's time to see the greenhouse."

The plants in the greenhouse looked rather ordinary. But the way in which they were grown was unique.

The boys, their father, and Mr. Bentson were guided through the greenhouse by one of the technicians, Mr. Katoyama. He showed them the miniature greenhouses within

Randy said, "You mean the plants take up the hot carbon?"

the main greenhouse, where radioactive plants could be grown.

"These little greenhouses are called nutriculture chambers," said Mr. Katoyama. "Look inside."

The boys stopped beside one that had been opened up. A technician sat inside on a little stool, working on some tomato plants.

"What're you up to today, Pete?" Mr. Katoyama asked.

"Labeling fruit," said the man. "We're tracing how the photosynthesis operation is involved in the ripening process."

"Notice how the plants grow in clean gravel," said Mr. Katoyama. "They're fed a solution containing all the elements they need for growth. The lights you see supplement sunlight and aid the photosynthesis process."

"I may be awful dumb," Sam said. "But what's photosynthesis?"

"That's a process by which plants make their own food. They take carbon dioxide out of the air, and absorb water from the ground, and turn them into starch and other products. Photosynthesis goes on only in the presence of light."

"Oh."

"We want these plants to be radioactive, so we grow them in these airtight chambers and supply them with radioactive carbon-14 in their carbon dioxide. The plants take in the hot carbon and use it to make up leaves, stems, fruit, and so on."

Randy said, "You mean the plants take up the hot carbon and use it as building blocks?"

"That's absolutely right," said Mr. Katoyama. "Now. Why do you suppose we grow hot plants?"

"Well, you could study photosynthesis," Randy said.

"That's one reason. We can track down the hot carbon

atoms with a counter and find out how fast they're being deposited in the plants, and where they go first."

"I don't know any other reasons," Randy said. "Can you tell us?"

"Or is it top secret?" Sam added.

"No secret at all," Mr. Katoyama laughed. "You know that plants make lots of different products that we use. Like drugs, rubber, starch, and sugar. Well, if you want to make these things radioactive, you can't just shove them into a reactor. You have to grow the plant in a radioactive atmosphere like we do here."

Randy said, "And the plant itself makes the radioactive material. Pretty sharp."

Mr. Katoyama stepped over to another small chamber. This one was in operation. It was closed tightly and water from a sprinkling system on top flowed continuously over its outside walls.

"Rubber plants are growing in here. We won't grow any big trees like they have in South America, of course, but even little plants like these give off latex when they're tapped. However, the latex from these plants will be radioactive. The study will help botanists figure out just how rubber is made by the plant."

"What's this water flowing over the greenhouse for?" Sam asked.

"That's to keep the temperature inside at a constant rate. It helps control the experiment."

Randy inspected some of the tomato plants that had been removed from their nutriculture chambers.

"I suppose these little tomatoes are full of poisonous carbon-14," he said.

Mr. Katoyama said, "The ones on this plant have only a little hot carbon in them. Not enough to hurt you. But if

you ate one of these tomatoes, we'd be able to trace its path through your body with a radiation detector."

"Tracer isotopes," Randy said suddenly. "The hot carbon would be a tracer isotope. I've read about them."

Mr. Bentson said, "There are many radioactive elements that can be used as tracers and followed through the body. Tracers are a wonderful new tool for biologists and medical men. They're helping us to find out how the body utilizes food and mineral substances, and how certain chemicals concentrate in various parts of the body."

Sam said, "Let me get this straight. If I ate one of these tomatoes, do you mean that you could follow the food around in my stomach with a geiger counter?"

Mr. Katoyama laughed. "We could ever follow it after it had been digested and passed into your bloodstream. And if you pricked your finger, and we examined the little drop of blood, we might find that some carbon atoms in it came from the radioactive tomato you ate yesterday."

"Wow!" said Sam. "First thing you know, there won't be *anything* about plants or animals that you haven't figured out."

Mr. Morrow said, "That day is still far away, son. But tracer isotopes have made it possible to learn much more about how living things function. Tracers can show how plants use water and fertilizers, how animals use their food, how diseases can be combated. More and more uses for tracers are being discovered every day."

They thanked Mr. Katoyama and headed back for the car.

Randy asked, "Tracer isotopes are used in other fields besides biology, aren't they?"

His father answered, "They certainly are. Chemists use them to trace complex chemical reactions. And oil com-

panies have a special use for tracers, too. You probably know that oilmen use their cross-country pipelines to transport different batches of oil, one right after the other. Previously, they had to take lots of samples to tell where one batch ended and another began. Today the oilmen simply add a quantity of tracer isotope when they start a new batch down the pipe. Its progress is easily traced with a geiger counter."

"I can see that tracers have a lot of possibilities!" Randy exclaimed. "Are radioisotopes used for anything besides tracers."

"You bet," said Mr. Bentson. "Some of them can be used like radium for treating cancer and other diseases. Then there are isotopes that are used like x-rays to inspect metal parts for flaws. Others can measure the thickness of materials like steel or even cigarettes. And in the next building we're going to visit, you'll see still another use for radioisotopes."

"What's that, Mr. Bentson?"

"We're heading for the high-level gamma facility. The isotopes used here give off extremely powerful gamma radiation."

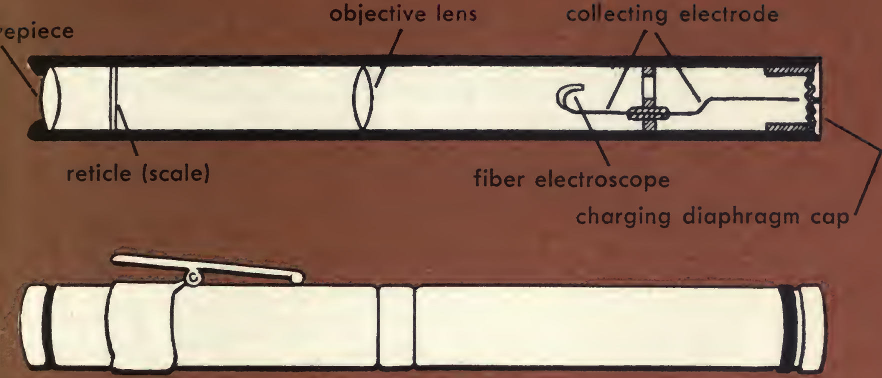
Sam made a few protesting noises when he found that this was one of the buildings he wouldn't be able to visit. But Mr. Bentson produced a batch of picture booklets for him to look at, and he decided not to feel too cheated at being left behind.

As Randy and Mr. Morrow entered the gamma facility building, Mr. Bentson explained that younger boys and girls might not understand that some of the materials in the building were dangerous.

"You'll see what I mean. It's perfectly safe for us, though."

They passed into a reception hall, where a young woman

One type of dosimeter

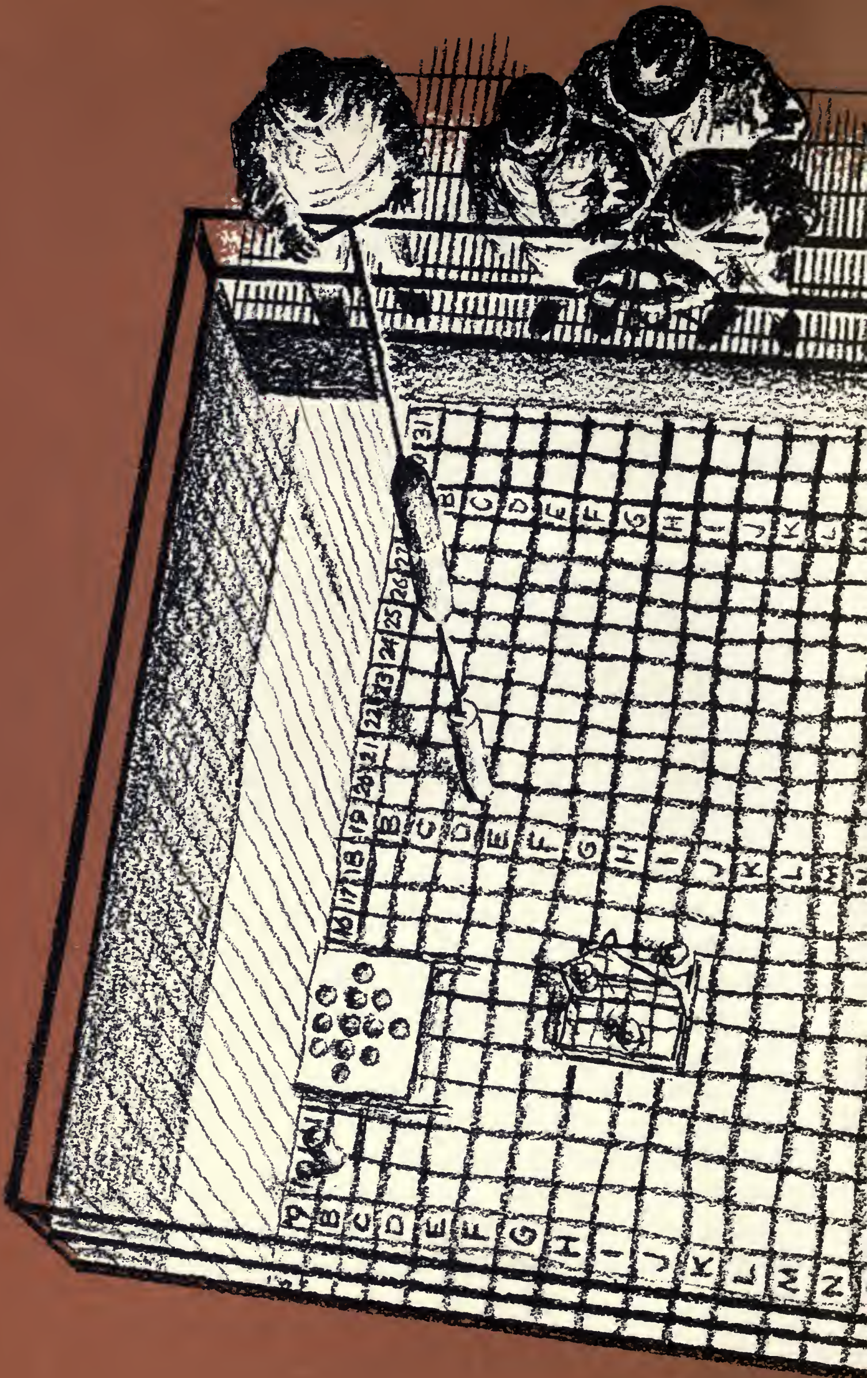


This type of dosimeter operates like an ordinary electroscope. A charge is placed on the fiber, which causes it to bend outward. If radiation is present, the fiber loses its charge and moves inward. The system of lenses make it possible to view the fiber against a scale that measures the radiation dose directly in milliroentgens of roentgens. These dosimeters are worn by people exposed to radiation.

handed each of them a dosimeter to wear on their lapels. The dosimeter was a little gadget about the size of a fountain pen cap. It would measure the amount of radiation each of the visitors was exposed to during his stay.

Randy was surprised when they entered the main room of the gamma facility. Sunk into the center of the floor was a deep pool of water that looked just like a swimming pool.

The technician in charge invited them to look down into the pool, which was surrounded by a guard rail. The water was very clear—so clear that Randy could hardly believe that it was 20 feet deep. The floor of the pool was marked off in squares, some of which were designated with num-



The technician invited them to look down into the pool.

bers and letters. Near the center of one side of the pool stood a metal rack.

"That rack contains spent uranium fuel elements from the National Reactor Testing Station in Idaho," the technician explained. "The elements are no good for reactors anymore, since they're full of highly radioactive fission products. But we find a use for these hot isotopes here."

The man explained that the elements gave off intense gamma radiation—over one million roentgens an hour. Many experiments could be performed using this intense radiation source.

"But what about the swimming pool?" Randy asked.

"The water shields *us* from the radiation. We wouldn't want to use concrete or lead shields here, since we have to see what's going on. So we use this deep water, which acts as a radiation shield just like lead. The water also cools the fuel elements. Let me turn off the lights for a moment."

Their host flipped the switch, then directed the Morrows to look down at the fuel element rack. Randy exclaimed out loud. An eery blue glow surrounded the entire rack.

"What is it?" he wanted to know.

"That's Cerenkov radiation," Mr. Bentson said. He pronounced it *chair-en-kof*. "The gamma rays coming from the fuel elements produce charged particles in the medium surrounding them—in this case, in the water. The particles move faster in the medium than light does, and give rise to that strange blue glow."

The technician turned the lights on again and explained the workings of the facility. The irradiation rack they saw on the floor of the pool contained 12 fuel elements, placed upright in cadmium-lined compartments. Between the fuel compartments were spaces in which samples could be inserted and irradiated.

"The samples are placed in these aluminum urns," the technician explained. He showed an urn to Randy. It was about 4 inches in diameter and over two feet long.

"The urns can be placed directly in the irradiation rack, or they can be located anywhere in the pool. That gimmick hanging in the pool that looks like a long pole is an urn grab. It brings the sample urns up to the surface of the water so they can be removed and examined. The basket you see in the corner of the pool is used to transport a number of urns at once."

"What does the gamma radiation do to the samples?" Randy asked.

"Well, you know that gamma rays are something like x-rays."

"Sure."

"They penetrate different materials and cause ionization and other effects. One of the most interesting effects of gamma radiation is the sterilization of foods. Gamma rays kill bacteria, mold, and fungi that cause food decay. Look over here on this table."

They were shown a group of food samples that had been sealed in plastic bags. A slice of bread that was untreated had become moldy and useless after six months' storage. A similar slice that had been subjected to the intense gamma radiation was dried out—but no mold or decay had affected it.

Randy examined some potatoes that had also been subjected to the gamma radiation. They showed less tendency to sprout and become rotten than ones that had not been treated.

"Doesn't the gamma radiation hurt the food? I mean, make it radioactive, or something?" Randy asked.

"No, it doesn't make food radioactive. But sometimes

the radiation will change the color or the taste, or change the vitamin content. These effects are being studied now. It may well be that some day most of our foods will be processed with gamma radiation instead of with heat."

Mr. Morrow said, "And then you'll be able to store little plastic packages of meat on the pantry shelves."

"I suppose you irradiate other kinds of materials besides food," Randy said.

"Certainly. Plastics show interesting changes when they're subjected to radiation. So do other chemical compounds. We receive materials here that are sent from all over the country. This high-level gamma facility is one of the services Argonne offers to other organizations."

On the way out, the Morrows and Mr. Bentson removed their lapel dosimeters and deposited them in a box. At the end of each working day, a health physicist would check the dosimeters to keep track of the amount of radiation received each day by the employees.

Randy stopped at a large upright device that resembled a soft-drink dispenser.

"What's this, Mr. Bentson?"

"This is a white monster. It measures radiation on your hands and shoes."

Mr. Morrow said, "Let's try it."

Randy read the sign: *Step on grill, insert hands, touch back plate with finger tips.*

Randy stepped up and inserted his hands into the two openings in the machine. A yellow sign lit up, saying: *Wait.* In a few seconds, a green sign lit up, saying: *Okay.*

"This is better than a pinball machine," Randy said.

Mr. Bentson smiled. "Notice the meters that give the count on each of your hands and feet."

Mr. Morrow and Mr. Bentson tested themselves, too, and

found that they were safe.

Randy asked, "What would we do if the machine showed that we were contaminated with radioactive material?"

"Strip!" said Mr. Bentson. "See that shower? Then you'd scrub! Then get out the brush and kitchen cleanser and scrub some more!"

Randy said, "I'm glad we got the green light!"

"The gamma facility is designed to be safe in operation," Mr. Bentson said, "but you can see why younger kids aren't allowed in here."

"I'll say," Randy agreed. "First thing some of 'em would do would be to fall into the pool."

"And that would be just too bad. Gamma radiation can be a useful friend when you respect it, but it's also a dangerous friend. You wouldn't stick your head into a roaring blast furnace—and you wouldn't dive into that innocent looking swimming pool for the same reason!"

After the gamma facility, the Morrows were shown a few chemistry labs. Randy peeked through the glass in closed doors and watched the scientists and technicians at work.

Somewhat to his surprise, he saw no extremely strange devices.

"I was expecting something a little more weird looking," Randy admitted. "These labs look like ordinary chem labs."

"They're different, though," Mr. Bentson said. "The chemists are protected from the radioactive materials they work with. You can see a plastic shield around that flask on the table. And the chemists wear gloves and take special precautions with the hotter materials."

Randy asked, "Is this kind of work any different from ordinary chemistry?"

"Frequently, our chemists have smaller quantities of material to work with. Then they have to use the techniques

The Morrows were shown a few chemistry labs.

of microchemistry, where even a drop has to be divided up. If the chemist is investigating some of the man-made heavy elements, there might not be enough of the chemical to smear on the head of a pin. Yet the chemist would have to make his tests with whatever he had."

"Wow!"

Mr. Morrow added, "And there's another funny thing about working with radioactive elements. Some of them have very short half-lives. How would you like to start an experiment, and find that your element had decayed away so that it was gone before the experiment could be finished?"

"Oh, brother," said Randy.

"What else do chemists do here?" asked Sam.

Mr. Benton thought a moment. "Well, you know about tracers, and how materials are irradiated with gamma rays.

We also study rare stable isotopes, and heavy elements and fission products. The man-made element number 100, called fermium after Dr. Enrico Fermi, was first produced right here at Argonne."

Mr. Bentson described many pieces of special apparatus that Argonne chemists and physicists worked with. There were spectrographs and spectrophotometers; mass spectrometers measured atomic weights with great precision; a battery of electronic computors assisted in mathematical calculations; a photolysis apparatus irradiated chemicals with ultraviolet rays; a unique bent-crystal spectrometer permitted studies of gamma rays.

"You're leaving me behind," Randy admitted with a wry grin. "There's so much to the atomic energy field—so many different areas to work in. How would a fellow like me decide what he might like to specialize in?"

Mr. Bentson said, "Let's wander over to the cafeteria and surround some lunch. And I'll try to explain the over-all picture a little better."

CHAPTER 12

Shall I be an atomic scientist?

THE FOOD, Randy found, was excellent. He chomped appreciatively on a piece of home-made strawberry pie and downed a glass of milk.

"This is real brain-food, all right," Randy said. "Makes me want to be an atomic scientist just so I can come here and eat!"

Mr. Bentson laughed. "People have a lot of reasons for entering the atomic energy field, but that's the first time I heard *that* argument!"

"Give us the straight stuff, Mr. Bentson," Sam said. "Why do guys become atomic scientists?"

"If you asked ten people around here that question, you'd get ten answers. Some of the boys would say they just like the pay! But I think the main reason has something to do

with a love for exploring."

"Exploring!" Sam said in surprise.

"In a way," Mr. Bentson went on, "that's what many of the scientists out here are doing. Those machines with the strange names—those complex equations you saw on the blackboards in the physics labs down the hall—they're like landmarks to an explorer in science, guiding him along the unknown road. These men and women like to ask questions like, what makes up the atom? Why does it behave like it does? What good is it? They use their brains and their tools . . . and sometimes they can find the answers."

"I guess an atom *is* a sort of frontier," Randy admitted.

"All knowledge is a frontier," Mr. Bentson said. "Some persons are attracted to one area, other persons to another. Atomic energy seems particularly attractive to young people because it's a new field needing new ideas."

Randy said, "I can see why you compare research in atomic energy to exploring. But not everyone out here can do research—"

"That's true, Randy. Hand in hand with research goes development. If you carry out the comparison with the explorer, the scientists engaged in development could be compared to the settlers that come into a new land after it's been opened up. Scientists in development use their ingenuity to make atomic energy useful and safe to work with."

Randy began to scribble rapidly in his notebook. "Research and development," he muttered. "Mr. Bentson, how about giving me a run-down on the different kinds of jobs in the atomic energy field?"

The Argonne man dictated a list, which Randy copied:

EMPLOYMENT OPPORTUNITIES IN THE ATOMIC ENERGY FIELD

Physics

Electromagnetic
Electron
Electrostatic
Molecular
Nuclear
  Cosmic Radiation
  Mass Spectroscopy
  Particle Acceleration
  Nuclear Particles
Radiological
Reactor
Weapons

Chemistry

Inorganic
  Analytical
  Metallurgical
  Nuclear
Organic
  Petroleum
  Physiological
  Synthesis
Physical
  Atomic and Molecular
  Cryogenic
  Electrochemical
  Radiation
Spectroscopy

Biology and Medicine

Agronomy
Bacteriology
Biochemistry
Biology
  Botany
  Genetics
  Microbiology
  Radiobiology
  Zoology
Biophysics
Cancer Research
Cytology
Health Physics
Immunology
Mathematical Biology
Pathology
Pharmacology
Physicians and Surgeons
Physiology
Toxicology

Engineering

Chemical
Civil
Electrical
Electronics
Mechanical
Metallurgical
Patent
Project
Reactor
Remote Control
Safety
Sanitary

Technical and Special Services

Administration
Astronomy
Classification
  Analysis
Civil Effects
Cybernetics
Foreign Literature

- Geology
- Graphic Arts
- Industrial Analysis
- Industrial Hygiene
- Industrial Information
- Industrial Specialization
- Inspection
- Maintenance
- Mathematics
- Mechanics
- Meteorology
- Production Analysis
- Scientific Analysis
- Special Materials
- Technical Library
- Technical Work

Sam peered at Randy's list and scratched his head. "Wow! Some of these angles are news to me! What's cryogenics?"

"Study of materials at extremely low temperatures," his father said.

"And how about agronomy and cytology and cybernetics?"

"Agronomy is the study of crops and soils. Cytology studies cells in living things, and cybernetics is concerned with computors and other mechanical and electronic devices that think."

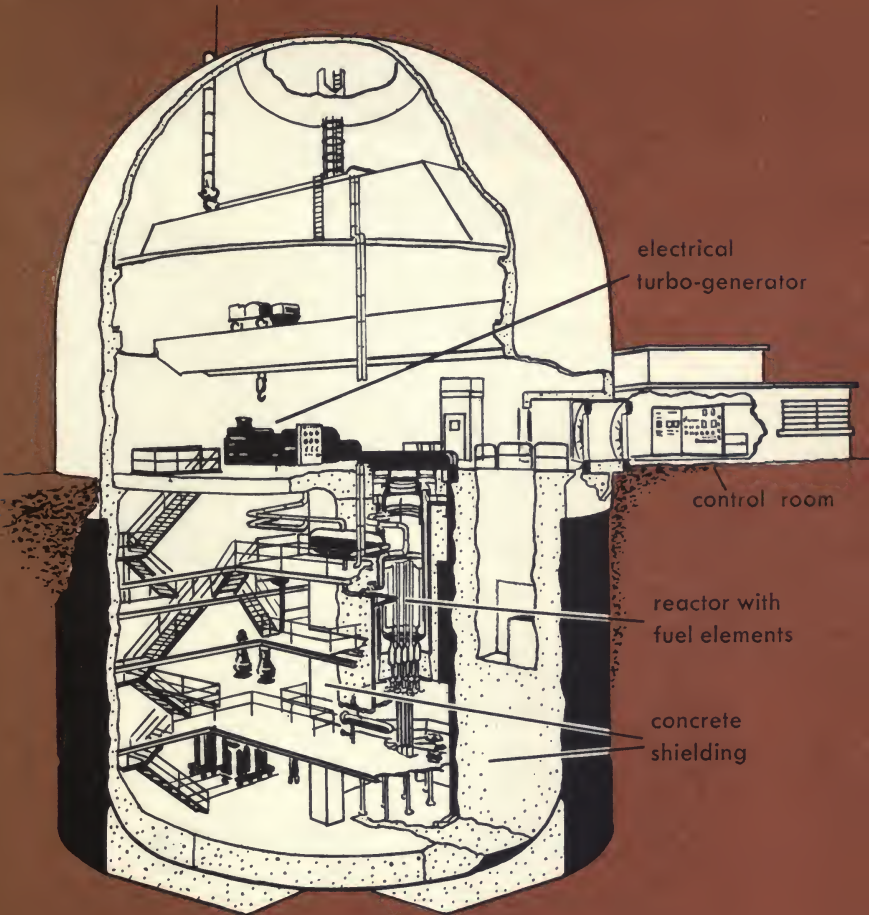
"Gee." Sam looked thoughtful.

Mr. Bentson rose from the table. "If you fellows are finished with your lunch, we'll look around a little more."

During the rest of the afternoon, the Morrows and Mr. Bentson visited many of the other buildings at Argonne.

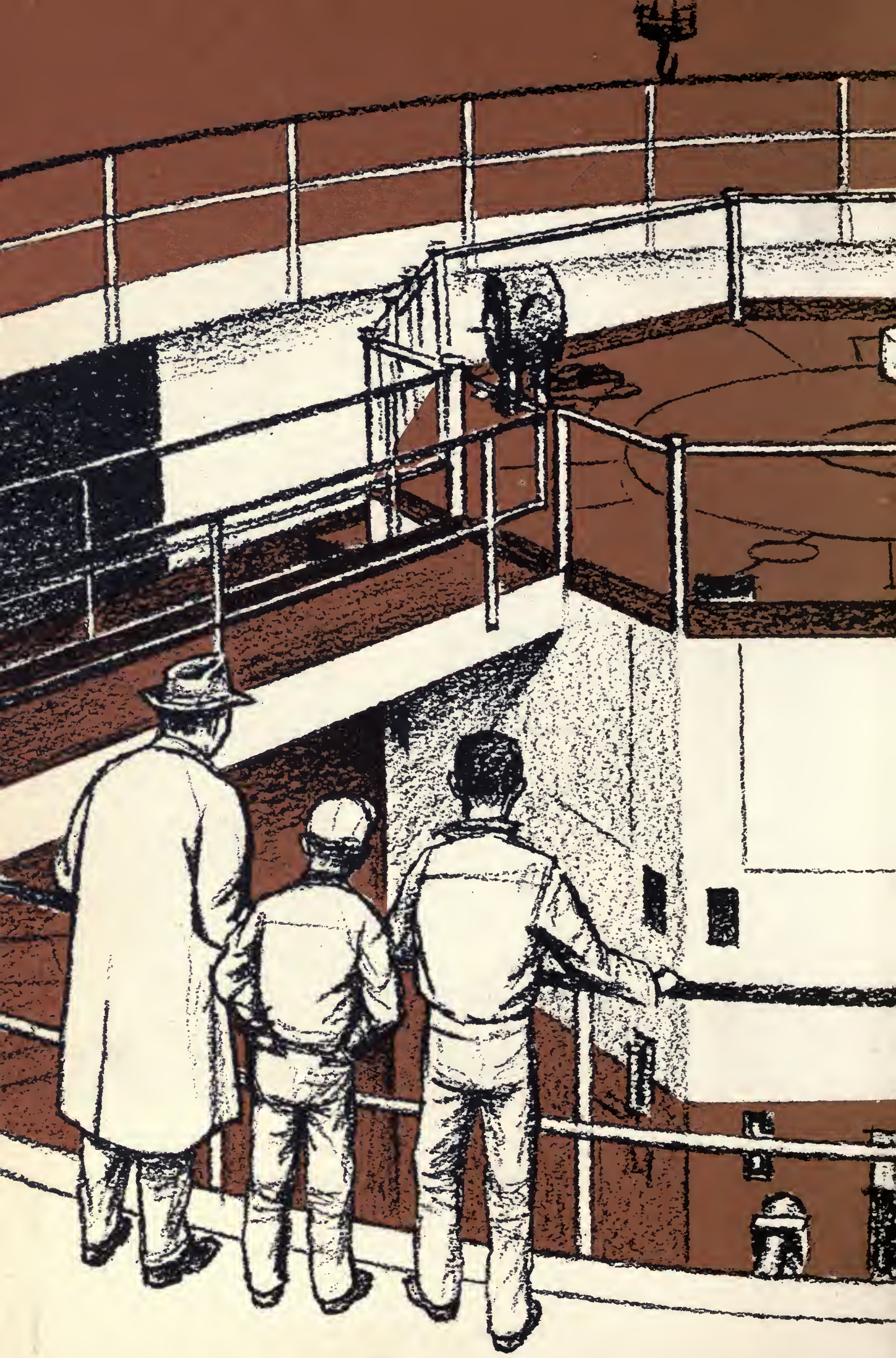
They saw the EBWR—the experimental boiling water reactor. It was the first nuclear power reactor to be completed in the civilian power reactor development program

EBWR—experimental boiling water reactor



Cutaway view of EBWR plant. Domed building is made of steel, designed to be operated by remote control.

of the A.E.C. The EBWR building was an unusual sight with its great dome-shaped superstructure.



The Morrows also visited the building

that housed the CP-5 type reactor.

Mr. Bentson explained, "The steel dome has great structural strength. It's unlikely that this type of reactor would have an accident. But if it did, the dome would prevent any radioactive material from escaping."

The EBWR was designed to be operated by remote control. The men who ran the power plant worked in a control and service building adjoining the dome-topped reactor building. The plant was able to generate 5,000 kilowatts of electricity, which was used by the Laboratory.

Mr. Bentson said, "Atomic energy doesn't produce electricity quite as cheaply as conventional methods yet. But that's one of the things we're working on here!"

The Morrows also visited the building that housed the CP-5, a large, heavy-water moderated research reactor. Standing on the catwalk surrounding the reactor, the Morrows looked down on many pieces of experimental apparatus clustered around the outer shielding.

Mr. Bentson explained that there were openings in the CP-5 so that experiments could be conducted with the neutrons that were produced. The reactor also produced intensely radioactive materials that were used in research at Argonne and elsewhere in the nation.

"I wish it were possible for me to show you our modern remote control manipulators," Mr. Bentson said. "Those are machines that enable scientists to carry on experiments with very hot materials. The manipulators are just like a pair of robot hands. You may have seen pictures of them."

"I did," Randy said. "The scientist just puts his hands into the special handles and moves them as though he were—say, stirring a beaker. Somehow or other the manipulator transmits the motion of the man's hand to the robot hand that really *is* stirring a beaker!"

"The real name for these machines is master-slave manip-

ulator," Mr. Bentson said. "Too bad they're doing classified work in that building now. I'd like to show you the caves where very hot materials are studied."

"Caves?"

"That's what we call the sealed rooms where dangerous radioactive materials are handled by robot hands. Our modern master-slave manipulators are operated by electronics. The operator can be hundreds of feet away from the slave hands. Old fashioned mechanical manipulators only had a working distance of about twelve feet."

"I sure wish I could see that," Sam mourned. "Of course, what'd really be great would be making one work!"

"Maybe the next time you visit us, you can try it," Mr. Bentson said. "I've operated one of the new-type manipulators myself. They're so sensitive that you can actually *feel* the object the robot hands are grasping. The slave hands transmit the pressure right back to the master hands."

The Morrows were anxious to see a cyclotron, and Mr. Bentson obliged. At this building, they were again given little lapel dosimeters by the receptionist. She requested them to leave their watches at her desk, since the great magnet of the cyclotron would ruin them.

"This is a 62-inch cyclotron," Mr. Bentson said. "It accelerates deuterons to an energy of over 21 Mev. Do you boys know how a cyclotron works?"

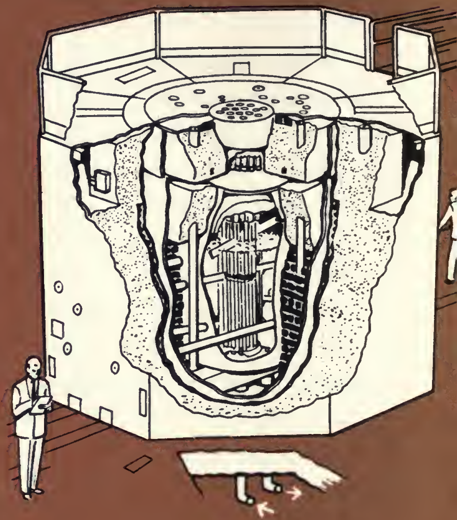
Randy nodded. "We know a little about it."

"This cyclotron is used mostly by our Chemistry Division. It's a moderately powerful instrument as particle accelerators go. You may have read about the big accelerator we now have in the planning stage."

Mr. Morrow said, "I wrote a short piece on it several months ago. Do they still plan to accelerate particles to the 15 Bev range?"

Argonne Laboratory's CP-5 reactor

The central aluminum tank of CP-5 contains 17 vertical fuel elements, encased in pipelike housings and immersed in heavy water. The latter cools and moderates the reactor. A two-foot-thick zone of graphite blocks surrounds the tank and reflects neutrons. The outer shielding consists of 4½ feet of extra-dense concrete. Note the ports in the side of the reactor. These make it possible to insert materials for irradiation by neutrons. Other special openings permit beams of neutrons to leave the reactor.



Mr. Bentson shrugged. "We'll try to do a lot better than that. Maybe we'll even get up to 50 Bev if we can lick the engineering problems. Actually, we're limited by the huge size of the magnet that would be needed by such a powerful accelerator. The 15-Bev model would need a magnet 600 feet in diameter. A more powerful machine would need a bigger one."

Mr. Morrow laughed. "You guys are going to find your magnet sinking down out of sight in this soil!"

"Don't think this hasn't occurred to the engineers," said Mr. Bentson ruefully. "A huge thing like that will have to be supported like a skyscraper."

Randy asked. "Will this new accelerator be the biggest

in the world?"

"Probably, unless some other country outdoes us. At present, the biggest accelerators are the California Bevatron with 6.3 Bev, and a Russian accelerator that jacks the energies up to 8 or 10 Bev. Brookhaven Lab in New York is building a model that should accelerate particles to 25 Bev."

"That's a lot of Bevs," Randy said.

"Cosmic rays have even more," his father said. "They commonly have energies in the 50-Bev range. A few fantastic particles have energies up to *100 million Bev.*"

"We'll be satisfied to reach even a fraction of that," Mr. Bentson admitted.

As they left the cyclotron building, Mr. Bentson pointed out a structure on the horizon that resembled a fire tower.

"That's an instrument tower for our radiological physics division. They study the radiation in the air, among other things."

"Is the air around here more radioactive than it is in other places?" Randy asked.

"Tests are always being carried on just to determine that, Randy. We measure the radioactivity in the air and in the soil and plants. Some of the boys even catch fish from the streams running through the lab grounds so that we can measure their radioactivity."

Mr. Morrow said, "You can see how carefully the health of the atomic energy workers is guarded. People sometimes get the idea that it's dangerous to work in atomic energy. Actually, Argonne's safety record is a good deal better than that of most industrial organizations."

"I saw some safety awards in some of the buildings we visited," Sam said eagerly. "They said things like *Two Years Without a Disabling Accident.*"

Mr. Bentson nodded. "A lot of our research is carried on

in the health physics field. And this kind of work is particularly rewarding."

Randy said thoughtfully, "Safe atoms. I suppose that in time the scientists and engineers in the atomic energy field could make all of the processes safe and foolproof."

"There's no reason why they couldn't," Mr. Morrow said. "I know what you're thinking, son. Atomic energy can be such a wonderful servant to man—why must it also have the potential to destroy him?"

"I was thinking something like that," the boy admitted. "On one hand there are the radioisotopes that treat cancer and the power plants that can raise the standard of living for even the poorest countries. And on the other hand are atomic weapons that can ruin everything we have in our civilization."

Mr. Bentson said, "But you must realize, Randy, that by itself the atom is as neutral as a flame. Fire can cook food or generate power. It can be a boon and a help to man. Or it can be a forest fire raging out of control, devouring everything in its way. Yet the flame in both cases is the same. Only the use it's put to differs."

"I can see that. . . ."

"Atomic energy is very similar. It can be used for good or for evil. But the motivation comes from man—not from the atom. Most of our projects at Argonne are devoted to peaceful applications of atomic energy. But we carry on some weapons research as well. We must do this as long as other nations persist in developing atomic weapons. You see why, don't you?"

Randy searched Mr. Bentson's anxious face.

"I do—and I don't," Randy said. "Maybe I'm just a kid with a lot to learn. I *do* see why we have to keep our stack of brickbats as long as the tough kid across the street builds

up his stack. But I *don't* see why our stack has to get so big that eventually it topples of its own weight."

"Men are working their hearts out, trying to solve that problem, Randy. But it's a task for statesmen, not scientists."

The Morrows drove Mr. Bentson back to the administration building where they were to say good-bye.

"This visit has really meant a lot to us, Mr. Bentson," Randy said. Sam echoed him.

"I'm glad you could see some of the work we're doing, boys. I hope you'll tell your friends about it. And I hope you'll think about entering the atomic energy field yourselves."

"When *I* grow up, I'm going to be a power reactor engineer," Sam said. "I already built one power reactor, Mr. Bentson. Out of tin cans and macaroni. It looked swell."

The Argonne man smiled. "I'll give you a booklet on our EBWR, Sam. You might want to make a model of it, too. How about you, Randy? Is there anything I can get you more information on?"

"I'd like to get a list of books on atomic energy."

Mr. Bentson promised to send him one. And then the Morrows thanked Mr. Bentson and said good-bye.

When they were on their way home again, Mr. Morrow asked Randy whether he'd decided to become an atomic scientist.

"Can't tell yet," the boy smiled. "I'm sure I want to get into some branch of science, though. I guess the best thing for me to do is study the field more and soak up all the science I can in high school and college."

"Sounds like a sensible plan."

"Atoms," Randy thought, settling back in his seat. He looked out the car window. Should he be an atomic scientist? There was adventure there, and the thrill of discovery.

There was satisfaction in the thought of conquering disease or bringing useful power to the world, fascination in the thought of devising new uses for isotopes or carrying out projects to make atoms safe servants of mankind.

The June sun shone over the orchards and fields of young corn that stretched away on either side of the highway. Atomic energy from the sun, bringing warmth and light and life.

Atomic energy released by man. It could also bring warmth and light and life, Randy realized. And he could help bring it about through working in the atomic energy field.

Lost in thought, Randy watched the bright shreds of cloud that raced swiftly over the blue sky, now and then obscuring the face of the sun.

THE END

TESTING YOUR ATOMIC IQ

by A. L. Ruess, Ph.D.

University of Illinois

Here are 33 questions based on the material which you have just read. They were constructed as an aid in giving *you* some idea of how well you now understand the basic ideas and concepts about atomic energy presented in this book. How well you do depends on many things: your reading skill, ability to understand and remember the main points, your familiarity with chemistry and physics, your own interest in science, and other factors.

As a suggestion, you might first go over the *Glossary* to be sure you are well acquainted with the terms and vocabulary. Then, on a blank sheet of paper, number 1 to 33 down the left-hand side. Opposite the number of each question put the letter of your answer. There is only *one* correct answer for each question.

It is expected that the average high-school student will have from 28 to 33 correct answers. If you are not yet in high-school, 22 to 27 correct answers is considered average. The correct answers are found at the end of this quiz.

1. The fundamental part of the atom from which atomic energy is derived:

   a) the neutrons b) the nucleus c) the protons

For questions 2 to 4 give the charge which is usually characteristic for each of these atomic components.

2. Proton — a) negative charge

3. Electron — b) no charge

4. Neutron — c) positive charge

5. Radioactivity can be measured by units known as:
a) ergs b) dynes c) roentgens

6. Of the three fundamental particles in the nucleus, which is the largest?
a) electron b) neutron c) proton

7. However, which of these three has the least weight?
a) proton b) neutron c) electron

8. The first person to see the nucleus of an atom with a high-powered microscope was:
a) Albert Einstein
b) no one has ever seen one
c) Enrico Fermi, "father of the atomic bomb"

9. Isotopes are elements that:
a) have the same number of neutrons but different numbers of protons
b) have the same number of protons and neutrons, but different numbers of electrons
c) have the same number of protons, but different numbers of neutrons

10. Electrons that are thrown off from unstable nuclei are:
a) beta particles b) mesons c) alpha particles

11. What does an electroscope measure? a) radioactivity
b) static electricity c) alternating current

12. An atom of hydrogen usually has a nucleus consisting of *one* proton. An isotope of hydrogen known as deuterium has in its nucleus: a) 2 protons
b) a proton and a neutron c) 2 neutrons

13. A particle in the nucleus that has a mass greater than an electron, but less than a proton, and about which little is really known:
a) meson b) polonium c) positive neutron

14. Which of the following instruments was designed to make the tracks of nuclear particles visible?
a) an oscilloscope b) a Wilson cloud chamber
c) a betatron

15. The atomic weight of an element is defined as the sum of its protons and neutrons. An element having an atomic weight of 234 and with 92 protons in its nucleus has how many neutrons? a) 316 b) 326 c) 142

16. An isotope of the same element in Question 15 has an atomic weight of 238. How many protons does it have in its nucleus? a) 94 b) 92 c) 144

Each of the words in Questions 17 to 25 must be matched with the letter preceding the correct statement in the column on the right. The statements in the right-hand column can be used only *once.* (Be careful! For some of the questions two answers seem to be correct, but if you pick the wrong answer the remaining one will not match correctly with any of the other questions.)

17. positron	a) makes radioactivity visible
18. alpha particle	b) particle accelerator
19. triton	c) element *Number 100*
20. spinthariscope	d) unstable isotope
21. plutonium	e) positive electron
22. fermium	f) little flash of light
23. cyclotron	g) helium nucleus
24. radioisotope	h) manufactured element
25. scintillation	i) hydrogen isotope

26. The process in which the nucleus of the atom is split and a small amount of matter is converted to energy: a) fusion b) fission c) confabulation

27. Professor Einstein's famous equation $E=mc^2$, is used to calculate:
a) the number of million electron volts in a given mass of U-235, or U-238
b) the rate of emission of neutrons in an atomic reactor
c) the amount of energy released when a given mass of matter is converted into energy

28. An important research tool used to study the process of photosynthesis: a) the spinthariscope b) radioisotopes c) the scintillator

29. When water is used as a *moderator* in an atomic reactor with U-238, its purpose is:
a) to absorb heat b) to stop the reaction
c) to slow down the neutrons

30. Electricity produced by using atomic energy:
a) is cheaper than by using conventional methods
b) is more costly than by using conventional methods
c) costs about the same as conventional methods

31. Probably the most important "tracer isotope" used at the present time in studying some of the processes of living organisms:
a) hydrogen-3 b) carbon-14 c) chlorine-34

32. Gamma rays can be exceedingly harmful, but one of their useful functions includes:
a) sterilizing food b) causing transmutations
c) increasing the life span of mice used in laboratory experiments

33. Most jobs in the atomic energy field are open to:
a) physicists and chemists

b) physicists, chemists, and biologists
c) many trained personnel besides physicists, chemists, and biologists

ANSWERS TO *TESTING YOUR ATOMIC IQ*

1. b	**10.** a	**19.** i	**28.** b
2. c	**11.** b	**20.** a	**29.** c
3. a	**12.** b	**21.** h	**30.** b
4. b	**13.** a	**22.** c	**31.** b
5. c	**14.** b	**23.** b	**32.** a
6. a	**15.** c	**24.** d	**33.** c
7. c	**16.** b	**25.** f	
8. b	**17.** e	**26.** b	
9. c	**18.** g	**27.** c	

Now that you have scored your answers, how well did you do? We hope that you did well. Remember, we all learn by making mistakes. If you had any wrong answers, *now* is the time to look back in the book, like any good scientist would, and find out how and why you went off the beam. There is a good possibility that once you get these mistaken notions cleared up you will remember the correct ideas and concepts for a long time to come.

Although it is not possible to make predictions in the case of every reader who takes this test, it is quite likely that if your score was average, or above, you probably have enough interest in atomic energy to do further study in this field.

GLOSSARY OF TERMS

Alpha Particle The nucleus of a helium atom

Anode The positive electrode in an electric cell

Atomic Mass The unit used for expressing the masses of individual isotopes of elements. Atomic weight and atomic mass are equivalent terms

Atomic Weight The weight of an atom of an element expressed on a scale in which the weight of the oxygen atom is exactly 16

Beta Particle An electron moving at great speed that is emitted by a radioactive substance

Betatron An apparatus in which electrons are accelerated to high speeds so that they form a narrow beam of beta rays

Calibration Act of measuring

Cathode The negative electrode in an electric cell

Cosmic Rays The rays with extremely high penetrating power produced beyond the earth's atmosphere. They are constantly bombarding the earth

Cyclotron An apparatus for accelerating particles

Deuteron The nucleus of an atom of hydrogen-2

Dyne A unit of force. The force which, acting on one gram, produces an acceleration of one centimeter per second per second

Electron A particle having a negative charge. Electrons in motion constitute an electric current

Electron Volt A unit of energy. A million electron volts equal about 16 ten-millionths of an erg

Electroscope An instrument for determining the presence of an electric charge

Element Any of the 96 or more varieties of matter which compose substances of all kinds. Examples: carbon, copper, gold, helium, iodine, iron, lead, neon, oxygen, sulfur, tin, zinc

Erg A unit of energy being the work done by one dyne acting through a distance of one centimeter

Fission The splitting of an atomic nucleus

Gamma Rays Similar to X rays but of shorter wave length

Ionization The act of converting into ions

Ion An electrically charged atom or group of atoms

Isotope An atom having the same number of protons in its nucleus but a different number of neutrons than another atom of the same atomic number

Meson A particle with a mass greater than an electron but less than a proton

Molecule A unit of matter

Neutron A particle having an atomic weight of one but no positive charge

Nucleus The central part of an atom (pl. nuclei)

Photosynthesis Formation of carbohydrates from carbon dioxide and water in the presence of sunlight by green plants containing chlorophyll

Positron A positive electron

Proton The nucleus of an ordinary hydrogen atom. Protons also are found in the nuclei of other atoms

Radiation The process by which energy is emitted from atoms

Radioisotope A radioactive isotope

Roentgen Unit of measurement of radioactivity

Scintillation Act of emitting quick flashes of light

Spinthariscope A device that makes radioactive disintegration visible as small flashes of light

Transmutation The conversion of one element into another

Triton The nucleus of an atom of hydrogen-3

Wilson Cloud Chamber An enclosure containing air or other gas saturated with vapor in which can be seen the path traversed by nuclear particles